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## Director's Message

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The research findings highlighted in this year's Project AIR FORCE (PAF) annual report represent the broad spectrum of work the Air Force has asked us to undertake. PAF addresses far-reaching and interrelated questions: What will be the role of air and space power in the future security environment? How should the force be modernized to meet changing operational demands? What should be the size and characteristics of the USAF workforce, and how can that workforce be most effectively recruited, trained, and retained? How should sustainment, acquisition, and infrastructure be streamlined to control costs?

PAF conducts research in four programs that represent core competencies:

**Strategy and Doctrine** seeks to increase knowledge and understanding of geopolitical and other problems in the national security environment that affect Air Force operations. PAF maintains expertise in defense strategy; regional analysis; the objectives and tasks of evolving joint operations; and the potential contributions of air and space power to joint operations, defense planning, and requirements for force development.

**Aerospace Force Development** identifies and evaluates ways in which technological advances and new operational concepts can improve the Air Force's ability to satisfy a range of future operational demands. This research involves assessments of technology feasibility, performance, cost, and risk. Studies focus on major force components needed in the future and the systems and infrastructure supporting their operations.

**Manpower, Personnel, and Training** concentrates on questions about workforce size and composition and about the best ways to recruit, train, pay, promote, and retain personnel. PAF's research encompasses the total workforce: active duty, guard, reserve, civilian, and contractor personnel.

**Resource Management** analyzes policies and practices in logistics and readiness; outsourcing, privatization, and contracting; the industrial base; planning, programming, and budgeting; infrastructure; and weapon-system cost estimating. The goal of this program is to maximize the efficiency and effectiveness of Air Force operations in a resource-constrained environment.

PAF also conducts research on topics that cut across all four programs, and we regularly respond to Air Force requests for help on time-urgent problems.

The research described in this annual report is wide ranging. Included among the topics are global basing, how to think and communicate about space-based weapons, integration of air and space capabilities in combat, finding and attacking difficult targets, combat support, flexible maintenance concepts, jet engine costing, toxic warfare, and geopolitics.

- We report on a global access and basing strategy that centers on increasing U.S. flexibility through the enhancement of overseas security cooperation, adjustments to force packaging to ameliorate the effects of less-than-optimal basing arrangements, and adaptive planning to cope with rapidly changing access demands.
- PAF addresses the myths and misunderstandings of space-based weapons by creating a sourcebook for information on space weapons. We do not present an argument for or against such technology. Rather we develop a common vocabulary to help ensure that debates and discussions are based on facts.
- Integrating command and control battle management (C2BM) for air and space is of particular importance to the Air Force in its role as the Department of Defense Executive Agent for Space. Under sponsorship of the Air Force directors for command and control, intelligence, surveillance, and reconnaissance, PAF research identifies the most relevant near-term C2BM integration issues for the Air Force.
- The Air Force is confronted by a difficult aircrew management challenge with respect to fighter pilots. We examine key factors that affect the Air Force's ability to provide training and experience for new pilots in operational fighter units, and we suggest policy options to address the growing problem.
- In the 1990s, the Air Force—along with the other military services—faced a manpower crisis in terms of both declining recruitment and retention. That crisis passed with the softening of the economy, an increase in recruiting resources, and pay raises. However, the Air Force determined that a closer look at its compensation system was necessary. In our initial assessment, we focus on two potential alternatives: skill pay and capability pay.
- The challenge of finding and attacking time critical targets (TCTs) has been evident in many of the operations the Air Force has undertaken since 1991. Based on our review of Operations Desert Storm, Southern Watch, Northern Watch, and Allied Force, we propose changes in procedures, detection, automation, and networking to improve performance across all missions involving TCTs.

- Historically, the United States has not been able to deploy large joint forces globally within timeframes of days or weeks. However, if the Army's current efforts to enhance its rapid-response power projection are successful, such deployment capability will finally be within reach. PAF considers the Army's planned transformation and its broader implications in terms of Air Force operations and force structure. Specifically, we examine whether deployment goals can be met with existing bases and airlift/sealift capabilities.
- Because they involve qualitative factors and because they are based on probable outcomes, effects-based operations (EBO) are difficult to incorporate in models. As a result they are often underrepresented in favor of more-tangible factors. U.S. military planners have become increasingly interested in EBO. We discuss our research regarding principles for integrating EBO into defense-planning analysis.
- The Air Force has reconfigured its combat organization to meet the expeditionary demands placed upon it—i.e., the ability to deploy and employ rapidly and effectively anywhere in the world and to sustain operations as required. Essential to operating effectively in this environment is a flexible and responsive combat support command and control (CSC2) structure. We describe concepts for improving CSC2 methods and processes, and we recommend ways in which the Air Force can transition to the new concepts.
- The ability of the Air Force to support combat operations is directly related to its ability to have an adequate number of maintenance personnel with the right mix of skills. The Air Force asked us to review its approach to determining manpower needs in aircraft maintenance. We discuss our findings regarding the simulation model used to estimate manning requirements and the Air Force regulations that are used to set ceilings on the available manpower hours. We then recommend ways for the Air Force to more accurately estimate maintenance manpower and provide for adequate training of that cadre.
- Jet engine intermediate maintenance (JEIM) is crucial in maintaining effective air operations. Traditionally, JEIM shops have been established at forward operating locations. Now that the Air Force has greatly reduced the number of permanent main operating bases overseas and has reconfigured its combat forces into expeditionary units that can quickly deploy from the continental United States, a rethinking of all support concepts, including JEIM, is required. For the past several years, we have reported on various aspects of our efforts to help develop new support concepts to meet the challenging operational needs of the Air Force. Here we focus on approaches for locating and operating JEIM shops in peace and war.

- Realistic cost estimates for military aircraft play an important role in developing sound budgets and in contributing to an effective acquisition policy. As part of our continuing cost-analysis support to the Air Force, PAF has helped develop an updated method for estimating military engine costs and identified technological trends that are likely to affect costs in the future.
- The extraordinary and rapid consolidation (some would say compression) of the U.S. aerospace industry between 1990 and 1998 has created concern among defense planners. This is particularly true with respect to innovation, which in the past was nurtured in second- and third-tier companies, and with respect to cost reduction because opportunities for competition have been reduced. This consolidation has been accompanied by increased numbers of alliances, teaming, and joint ventures with foreign companies. PAF is assessing the extent of globalization in the aerospace defense industry and its implications for U.S. defense planning.
- Under the sponsorship of the Defense Advanced Research Projects Agency, an innovative acquisition strategy was introduced for the development of high-altitude, long-endurance unmanned aerial vehicles. (The program that eventually transitioned to the Air Force is Global Hawk.) We discuss the overall effects of this strategy and its applicability to other acquisition efforts.
- PAF research on toxic weapons and toxic warfare was well underway prior to the terrorist attacks on the World Trade Center and the Pentagon. Toxic chemicals and industrial waste are easily obtained, take little training to use, and can produce serious consequences. Our research indicates that toxic weapons merit greater attention as part of U.S. military and civilian crisis-response planning.
- It is well known that, since the end of the Cold War, Russia has been in a relative state of decline. We describe ways in which the United States can best prepare for the possible dangers inherent in Russia's downward spiral. We also propose a new focus in U.S. policy and planning with respect to Russia that could help limit the extent of its decline through various forms of cooperation.

Our research on the Air Force's role in the global war on terrorism continues, as does our technical and operational analysis of the mix of manned, unmanned, and space-based systems for conducting intelligence, surveillance, and reconnaissance operations. Because this work is classified, it is not described in our annual reports, which are public-domain documents.

As set forth in its charter, PAF focuses on matters of enduring interest and importance to the Air Force. Accordingly, our fiscal year 2003 research agenda includes

such topics as global strike, future air-ground operations, the Islamic world after 9/11, concepts of operations for national space strategy and for command and control of global task forces, responsive space launch, future force posture for Pacific Air Forces, achieving and sustaining required personnel mixes, aging aircraft, purchasing and supply-chain management in depots, wartime support options, and weapon-system costing.

PAF's research continuously contributes to a deep and rich reservoir of knowledge. We honor and protect the special and privileged relationship we have with the Air Force; and we value above all else our ability, through our research, to contribute to the security of our nation.



Natalie W. Crawford  
Vice President, RAND,  
and Director, Project AIR FORCE

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## A Global Access Strategy for the Air Force

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In the intricate geopolitical landscape of the 21st century, the United States requires its military forces to be both responsive and effective in the face of quickly evolving and often unforeseen contingencies. As a result, like the other military services, the Air Force has faced many new challenges in its efforts to increase its contributions to deterrence, crisis response, and warfighting. It also has a role in peacekeeping and humanitarian efforts.

For most of its history, the Air Force relied heavily on a sizable number of overseas bases. After the Cold War, however, with bases closing and global priorities shifting, the Air Force reconstituted itself as an expeditionary force, able to rapidly respond to dynamic situations with swiftly deployable units. Yet such a reconstitution has raised an important question: How can the Air Force remain a valuable and vigilant force overseas with a limited number of bases for its wide-ranging aerial fleets and with potentially limited global access?

In response to these concerns, Project AIR FORCE (PAF) researchers developed recommendations for a global access and basing strategy. Their analysis outlines an approach that focuses on increasing U.S. flexibility through the enhancement of overseas security cooperation, adjustments to force packaging to ameliorate the effects of less-than-optimal basing arrangements, and adaptive planning to cope with rapidly changing access demands.

### **Access Is a Growing Problem**

The USAF's difficulties in securing adequate access has a long history but became most apparent in a series of Persian Gulf crises between 1990 and 1998. These problems are expected to increase for three main reasons. First, even failed or weakened nation-states have generally proven capable of retaining control over their physical territory, thus limiting or prohibiting the use of their land and air space for U.S. military operations. Second, the crises expected to arise in the coming years are likely to occur in locations where the United States will confront substantial access uncertainties, such as Southwest Asia, the Taiwan Strait and South China Sea, and South Asia, as well as Africa, which may be the site of many humanitarian emergencies. Third, the threat to air bases posed by surface-to-surface missiles is expected to grow and may impel planners to base air forces farther from enemy territory.

## Nations Weigh Many Concerns in Making Access Decisions

A survey of the past and present record of global access suggests that three recurrent factors seem to favor a nation's cooperation with U.S. access needs: a desire to strengthen ties with the United States, the existence of close alignment and military connections, and shared interests and objectives.

The United States has substantial military ties with European states, which usually makes access easy to secure there. Even close allies, however, can disagree, and those occasions on which the United States was forbidden access are revealing. During military operations in the former Yugoslavia in 1999, for example, NATO member Greece refused to allow the NATO alliance's combat forces to fly over its territory or use its bases. In contrast, non-NATO nations such as Albania and Bulgaria did permit overflight. Thus, participation in NATO and even a history of cooperation with the United States do not guarantee access. Other factors instead came into play: Bulgaria valued gaining favor with NATO over any risks it might take in offering access, whereas Greece braved NATO's anger rather than risk internal public opposition and exacerbated tension with Turkey.

As is apparent in the case of Greece's unexpected refusal, close alliances—even those stretching over long periods of time—are not always enough. Three primary factors can result in a refusal of access:

- *Conflicting goals and interests.* For instance, Greece's denial was based in part on different visions of what constituted "stability" in the Balkans.
- *Concerns over domestic public opinion.* Greece's significant ethnocultural linkages to the Serbs, for example, fueled high levels of internal public opposition to the bombings.
- *Fears of retaliation via either terrorist acts or economic pressure.* During the 1973 airlift to Israel, for example, Britain, Spain, and other European nations refused to allow U.S. forces to fly over their territories in the face of possible cutoff of oil from Arab states.

## Information Sharing and Plain Dealing Can Result in New Access Partnerships

Despite these seemingly daunting inhibitions to access, tools of persuasion exist to help overcome them. First, the United States should consider projecting a stance of *transparency* in terms of its motives such that other nations are encouraged to trust U.S. objectives in a region. In addition, the United States should ini-

tiate as much *information sharing* as possible to help convince friends and allies that their interests do not in fact conflict and that cooperation aligns with their own goals. For instance, after the Iraqi invasion of Kuwait, sharing intelligence of Iraqi troop movements convinced the Saudis to admit U.S. forces. Keeping lines of communication clear and maintaining a reputation for honest, plain dealing will go a long way in allaying the concerns of potential partners.

Further, *engagement* is a valuable tool, particularly with countries with which ties are uncertain or weak. Actively engaging potential partners will help establish the United States as a nation for which it can be beneficial to do favors because those favors can be returned in times of crisis. To achieve this end, the military needs to maintain a lively dialogue with other nations' militaries and use its "information dominance" to help shape perceptions of the United States as a "good friend" with worthy objectives.

Of course, the United States may be able to influence other nations' views, but ultimately decisions over access will always be affected by constraints of the moment. Therefore, the United States cannot rely on even its closest relationships for the necessary access in any contingency. Instead, the Air Force, and the U.S. military overall, must *diversify*, and combine plain dealing with an increased flexibility in terms of operation and deployment options so that a wider array of choices is available.

### **Enhancing Flexibility Can Help When Access Is Less Than Optimal**

It is inevitable that situations will arise in which basing is not optimal and forces are deployed far from their intended targets. Conducting operations over such distances is a drain, both on the crews who must endure long missions and on the aircraft. Combat capabilities are adversely affected by these conditions.

To investigate the potential for long-distance basing, PAF researchers developed a scenario involving a U.S. air expeditionary task force (AETF) responding to an Iranian attack on Kuwait and Saudi Arabia. The researchers found that, in the short run and despite all the limitations associated with long distances, modest increases in the ratio of aircrew to aircraft and in the amount of air-to-air refueling support should allow USAF forces to operate with about the same effectiveness from ranges of 1,000–1,500 nautical miles to target as they can from 500 nautical miles.

Ultimately, the farther an AETF can project effective combat power, the more options commanders will have for dealing with exigencies such as increasing enemy missile capability, uncooperative regional partners, or inconvenient geography. Further, if expeditionary operations are truly the wave of the future, the USAF may want to acquire a fleet of combat aircraft better suited to the demands of long-range operations. The more choices at commanders' fingertips, the greater the chances are of rapid and successful engagement.

### **Access Needs in Peacekeeping and Humanitarian Operations Should Not Be Underestimated**

In the last ten years, U.S. forces have begun to take on, with mounting regularity, missions focused on humanitarian aid, peace enforcement, crisis response, and sanction enforcement. Although these situations are often resolvable through ad hoc deployments, experiences in Somalia (1992–1993) and Rwanda (1994) have demonstrated that the United States may find itself involved in a demanding crisis—specifically, a major peacekeeping or humanitarian mission centered in a remote locale with limited infrastructure. In such a case, access and basing considerations are just as critical as they are in more traditional military operations.

In fact, future humanitarian or peacekeeping missions could prove highly demanding and require more attention and planning than in the past. As with combat operations, flexibility is paramount given the complexities at work in a region, from scant resources to complicated ethnic and historical divisions. Also crucial in humanitarian operations, as in war, is the maintenance of strategic relationships with important nations (such as Egypt and Kenya, in the case of Africa) and the development of stronger relationships with other potential host nations. The more the USAF can prepare—logistically, strategically, and diplomatically—the faster it will be able to respond and the greater number of options it will have in carrying out its mission.

### **A Workable Global Access Strategy Is Possible**

Thus, while means do exist to surmount many individual obstacles to access, an overall strategy that will expand operational and strategic flexibility is clearly needed. “Pure” approaches toward managing future access and basing are possible, including increasing the number of overseas main operating bases, having a greater variety of potential partners, negotiating long-term extraterritorial access to bases known as “Rent-a-Rocks” (as was done with Guantanamo Bay and with

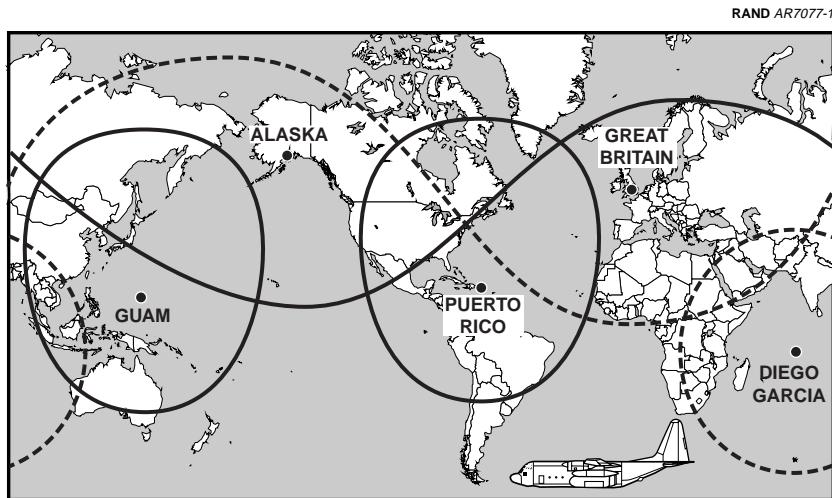
Diego Garcia, which greatly helped the U.S. position in the Persian Gulf), and escalating the use of U.S. territory as a launching pad for overseas operations.

Each of these “pure” approaches, however, is limited. For example, 90 percent of the force structure consists of fighters that cannot effectively sustain combat operations from U.S. territory in most scenarios. None of the approaches provides a complete solution to the access problem. Instead, the researchers suggested that the Air Force consider a metaphor from the financial world and treat the creation of its access strategy as a problem of *portfolio management*.

### Wall Street Supplies a Useful Metaphor

Much like the average American investor, the Air Force faces an uncertain environment that requires *diversification*. That is, it should not rely on a handful of seemingly reliable partners. Moreover, its small number of bases in a few areas of the globe prepares the nation for a limited range of overseas crises. As a result, the Air Force needs to diversify its portfolio—its partners, alliances, capabilities, and engagement options—in order to manage risk and take advantage of opportunity. Further, as on Wall Street, *information flows* are critical to assist in good decisionmaking, whether in determining investment goals or in understanding the complex interests of various nations. With this financial analogy in mind, the researchers formulated a sample “portfolio” with three components:

- *Make core investments.* In particular, three secure, low-risk investments hold much promise. First, the United States should maintain its current array of overseas bases in Europe and Asia. Second, the Air Force should establish a small number of forward support locations (FSLs) around the globe that could be used to house equipment and munitions, while also serving as repair facilities and airlift hubs when needed. At a minimum, these bases should be located in Alaska, Guam, Puerto Rico, Diego Garcia, and Great Britain. Figure 1 demonstrates the coverage these base locations could provide. Third, the United States should work at maintaining and expanding its contacts with key security partners through such joint activities as training exchanges and temporary deployments. Engagement of this kind is a worthy “investment” for any future crises.
- *Hedge against risk.* Air Force planning needs to anticipate and be more responsive to access constraints. Critical hedges might include the planning for and provision of extra tankers and aircrew for expeditionary forces deploying from long distances, or the development of high-speed, long-range strike platforms.



NOTE: The circles on the map are 3000 nm in radius; the planning factor for a C-130 is 3200 nm with a 12-ton payload. Solid circles denote an FSL on U.S. territory, while dotted ones indicate foreign FSLs.

**Figure 1—Coverage Available from Five Forward Support Locations**

- *Watch for new opportunities for partnerships.* The Air Force should encourage the U.S. government to pursue new and underappreciated opportunities for partnerships. For instance, building relationships with Kazakhstan, Mongolia, Malaysia, and even Vietnam could be of great benefit if a crisis developed in Asia. The Air Force might also begin scouting partners for potential “Rent-a-Rock” agreements in strategic areas.

### A Hybrid Approach Promises the Necessary Flexibility

There is no “silver bullet” to solve the USAF’s access problems; and any improvements will require significant costs, both in terms of money and opportunity. On the other hand, the research findings suggest that hurdles to access are manageable, and even the fallout from unimagined future crises can be minimized through a well-thought-out global access strategy. The hybrid strategy that the researchers recommend calls for, above all, increased flexibility—logistically, strategically, and operationally. The payoff will be a greatly enhanced robustness against unforeseen risks.

MR-1216-AF, *A Global Access Strategy for the U.S. Air Force*, David A. Shlapak,  
John Stillion, Olga Oliker, Tanya Charlick-Paley

## Informing the Debate on Space Weapons

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The United States appears to be due for a major debate on the use of space-based weapons in terrestrial conflicts. Recent military discussions give the impression that such weapons are inevitable. Space-based laser technology will eventually be able to demonstrate the ability to destroy missile targets. In addition, the possibility that other nations will decide to acquire space weapons makes discussion in the United States all the more pressing. A modest number of space-based weapons possessed by another country could challenge the United States' ability to project power around the globe and could mount a high-leverage, asymmetric response to U.S. military strength.

Despite the need for such a discussion, the subject of space-based weapons brings with it a host of myths and misunderstandings. PAF addressed this problem by creating a sourcebook for information on space weapons. The report does not present an argument either for or against such technology. Instead, it establishes a common vocabulary to help ensure that debates and discussions are fact-based. The report classifies and compares space weapons and explains how they might be used. It also explores ways in which the United States and other countries might decide to acquire them. The study concludes that, before deciding to acquire or forgo space weapons, the United States should fully discuss what they can do, what they will cost, and the likely consequences of possessing them.

### Different Technologies Offer Various Capabilities

“Space-based weapons” generally includes several distinct classes of weapons. The four categories reviewed in this study are indicated below.

- *Directed-energy weapons.* These weapons destroy targets using energy transmitted at the speed of light over long distances. They can be used as electronic jammers or laser cutting torches and can be employed against targets on or above the earth's atmosphere.
- *Kinetic-energy weapons against missile targets.* These weapons rely on kinetic energy (the energy of a body in motion) to impact a target at high speeds. Strikes against missiles take place above the earth's atmosphere.
- *Kinetic-energy weapons against surface targets.* In a similar way, using their own kinetic energy, these weapons destroy targets on the ground. However,

because they must survive reentry into the earth's atmosphere, they attack at very high speed and fall at a nearly vertical angle.

- *Space-based conventional weapons against surface targets.* Potential space-based conventional weapons vary widely. They can strike a broader range of targets than space-based kinetic-energy weapons can. They are also more responsive than are space-based kinetic energy weapons. Because they do not require a steep reentry angle, they can be based at lower orbital altitudes. They take only a few tens of minutes to deploy in the atmosphere, plus whatever time is required for munitions to reach their target(s) on the ground. In contrast, space-based kinetic-energy weapons for ground targets need times on the order of a few hours, depending on their base orbit altitude.

## **Space Weapons Should Be Viewed as Part of Other Military Functions**

One could imagine special, limited cases in which space-based weapons could be employed by themselves, but they would be most effective used in combination with other forces. Decisionmakers should consider these functions before deciding what kinds of weapons to acquire. For example, should a space-based weapon be highly maneuverable with only two or three "silver bullet" submunitions, or should it be less mobile but carry a larger load? Decisions such as these should also take into account how opponents might react to space technology in real-world situations. An enemy might respond to space-based missile defenses by saturating them with decoy targets. In this case, the United States would need to formulate a tactical response using all of its counter-air functions. If properly coordinated, space weapons and land-based conventional weapons could assist each other in neutralizing enemy defenses or communications.

In addition to these questions, the military must consider how space weapons should be commanded. If the level of command is too low, then the commander may not be aware of how his decisions affect resources or impact other operations. If the level is too high, then the commander may not be able to foresee collateral effects in the theater. It stands to reason that, if space weapons are to be coordinated along with other military functions, the commander who has tactical control over ground-based forces should also have control over the space assets that contribute to his mission.

## **The United States and Other Countries Could Find Reasons to Acquire Space Weapons**

Although there is currently no compelling threat to U.S. national security that could not be deterred or addressed by other means, some circumstances might persuade the United States to acquire space weapons. Possibilities include

- defending against a threat to national security posed by an adversary who is undeterred by other capabilities;
- responding in kind to the acquisition of space weapons by another nation, whether ally or adversary;
- acquiring space weapons in coordination with other nations to forestall, control, or influence their independent acquisition of such weapons;
- unilaterally acquiring space weapons to demonstrate global leadership, to protect U.S. and allied economic interests, or to improve the efficiency and effectiveness of military capability.

Given this range of possible circumstances, the United States might consider space-based weapons as part of its vision of global power projection for 2010 and beyond.

PAF researchers also assessed the circumstances that might persuade other countries to acquire space weapons. They found that, although motives and opportunities exist, there is no immediate, compelling threat driving any country to choose space weapons, unless it is the United States' overwhelming advantage in terrestrial capability. Nevertheless, the United States should be aware that countries like India and China, which have modest space abilities, could acquire the technology, resources, and command and control capabilities for space weapons that would pose a threat to U.S. interests. Regardless of whether the United States decides to acquire space weapons, U.S. policymakers need to anticipate which countries might acquire them and how the United States would respond.

## **Space Weapons Pose Advantages and Drawbacks**

The U.S. public and its policymakers should weigh the advantages and limitations of space weapons before deciding whether or not to acquire this technology. The major advantages include the following:

- *Space weapons extend access and reach.* Weapons in orbit can access a target virtually anywhere on the globe without political constraints such as over-flight and passage rights.
- *They are more responsive than weapons deployed on earth.* It takes less time to move a space weapon into position than it takes to deploy a weapon into a theater of operations. Once on orbit, space weapons are moved into position for attack both by their orbital velocity and by the earth's rotation underneath them. Multiple space weapons would be based in multiple orbital planes to be sure of having one in timely reach of targets.
- *They are distant from other weapons and bases.* The distance of space weapons makes them less vulnerable to attack. It also helps to distinguish them from ballistic missiles carrying nuclear weapons.
- *It is difficult for enemies to defend themselves against them.* This is particularly true of space-based kinetic-energy weapons, which strike at very high speeds.

The limitations to consider are as follows:

- *Space weapons make for static defenses.* Once in orbit, space weapons cannot be easily moved quickly to different orbital locations. Movement to different orbital planes is normally prohibitive. Thus, an opponent may be able to saturate the weapons with missiles or other space-based weaponry.
- *Their movements are predictable.* Satellites can be seen in orbit, and their paths are largely fixed. Enemies may attack them more easily if they have weapons capable of reaching them at orbital distances and velocities. However, few potential adversaries currently have the ability to confidently attack such relatively small objects in orbit.
- *They are expensive to launch and to remove from orbit.* Launching space weapons requires more logistical effort than launching a ballistic missile.
- *They must be deployed in large numbers to be responsive.* A constellation of space weapons is required to ensure that at least one will be in the right place when it is needed. The number of weapons may vary from a few to several dozen, depending on target urgency and weapon reach.

MR-1209-AF, *Space Weapons, Earth Wars*, Bob Preston, Dana J. Johnson,  
Sean J.A. Edwards, Michael Miller, Calvin Shipbaugh

## Integrating Space Capabilities into Theater Air Operations

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U.S. space systems include a number of satellites intended to enhance military forces in the theater. Today, such systems warn of theater missile attack, furnish data regarding weather conditions over targets, support precise positioning and navigation, and carry communications. Theater commanders also use data from satellites that provide national intelligence, surveillance, and reconnaissance (ISR) information. In practice, making data from space systems usefully available to theater forces has been a challenge. Nonetheless, with each successive conflict involving U.S. armed forces, theater commanders have become more appreciative of the utility of U.S. space systems.

If theater air forces in future conflicts are to fully exploit U.S. space assets, then command, control, and battle management (C2BM) for these assets will have to be better integrated with C2BM for air forces in the theater. C2BM includes assessment, planning, execution monitoring, and control of forces; and it is carried out by various organizations and systems according to established concepts of operations. To date, C2BM for air forces and C2BM for those space assets managed by the Department of Defense (DoD) have evolved separately. Moreover, many space assets for military use are not owned by DoD. For example, most space systems for ISR are managed by the National Reconnaissance Office, and the weather satellites are managed jointly by the Departments of Commerce and Defense and the National Aeronautics and Space Administration.

Air-space C2BM integration is of particular interest to the U.S. Air Force in its new role as DoD Executive Agent for Space, in which the service will be responsible for cradle-to-grave stewardship of military space systems. Under sponsorship of the Air Force directors for C2 and for ISR, PAF researchers identified the most relevant C2BM integration issues for the Air Force in the near future.

### Current Integration Needs Improvement

DoD space assets are under the control of the Commander, U.S. Strategic Command (USSTRATCOM),<sup>1</sup> whereas theater air forces are controlled by the

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<sup>1</sup>Formerly, U.S. Space Command controlled DoD space assets. On October 1, 2002, U.S. Space Command and U.S. Strategic Command merged into an expanded USSTRATCOM.

regional unified command commanders (UCCs). Integration of C2BM across these two chains of command has been ad hoc. Commander USSTRATCOM authorizes his space component commands (e.g., that for Air Force space assets) to undertake direct liaison with the regional UCCs and their subordinates, such as the joint task force commander or his air component commander. Thus, an air and space operations center (AOC) under USSTRATCOM in the United States may communicate with the joint AOC in the theater, or a team of U.S. Strategic Command space specialists may be assigned to the theater center. These personnel have access to separate computerized battle management systems for space and air forces and transmit data manually from one to the other. Such transfers are error-prone and time-consuming, but electronic linkage will soon be in effect.

Ad hoc integration has so far not jeopardized the effectiveness of air and space operations against adversaries, perhaps only because recent adversaries have not attempted to interfere with U.S. space assets. Should an adversary manage, for example, to jam Global Positioning System (GPS) signals used for precise positioning and navigation, U.S. force effectiveness could suffer from the lack of more formal C2BM integration. Because no concept of operations for navigation warfare has been developed, it may take longer than necessary to neutralize the source of disruption or mitigate its effects.

Also, lack of standard procedures and metrics for assessing the ability of U.S. space systems to support theater air operations and lack of full integration between space and theater battle management software mean that joint force air component commanders do not always know how the space system's current capability will affect their ability to plan and execute a mission. For example, if GPS accuracy were degraded, the air component commander might not receive this information in terms he can understand and relate to or soon enough to scrub a mission dependent on GPS-guided weapons. He might subsequently rely less on such weapons, even though space support for them might then be available.

To address the challenges of integrating air and military space forces, the Air Force should

- design and implement procedures for assessing the status of U.S. space systems with respect to support of theater air operations. The assessment should account for mission objectives, adversary actions to interfere with U.S. space systems, and theater environmental factors and constraints.
- develop a concept of operations for navigation warfare, train theater weapon system operators to report local GPS disruptions, and design a process for

collaborating with USSTRATCOM's GPS Support Center to resolve those disruptions.

- formulate procedures for increasing the integration of air and space force planning and execution to negate adversary actions against U.S. space systems, particularly communications systems and GPS.

### **Space Situational Awareness Should Be Enhanced**

Because of U.S. dependence upon space, the potential for adversaries to use space, and the need for U.S. space superiority, theater commanders need space situational awareness (SSA). However, knowledge of U.S. and adversary space systems is not enough to provide adequate SSA. Today's commercial, multinational environment demands that SSA include the operational status and location of any foreign space assets that could affect theater operations. Theater commanders will require intelligence assessments on how an adversary could utilize these assets, together with updates on any change of status or utilization of these space systems. They will also need information on U.S. options and initiatives to prevent these systems from being used against the United States.

The lack of adequate SSA needs to be addressed as adversaries begin to oppose U.S. space forces and to increase their use of commercial systems and their own national systems. This problem will become more severe as the United States and other nations develop and field new taskable, multimission space systems. To meet the evolving SSA challenge, the following issues need to be addressed by USSTRATCOM or the Air Force or both:

- Define the elements of a common operational picture for space and determine who should assemble it.
- Determine how the picture can be tailored for theater use and disseminated to theater AOCs.
- Identify the best approach for improving surveillance of space.
- Assess whether additional space intelligence capabilities should be provided to theater AOCs.

Addressing SSA issues should be a top priority. Without such awareness, theater commanders will not have the information they need to plan and execute their missions with assurance, nor will they fully understand the true threat posed by non-U.S. space systems.

## New Space Systems Pose Several Challenges

Situational awareness is only one of the challenges raised by the new space systems. These systems will be taskable—that is, it will be possible to focus them on particular areas of interest based on their priorities. They will also serve multiple missions and multiple users. For example, the Space-Based Infrared System (SBIRS) will support both theater operations and national missile defense. Space-based radar will serve users in the armed services and in the intelligence community.

If capabilities are to be maximized, it will be essential to develop concepts of operations, procedures, and systems for integration with air operations. The integration will have to be responsive to quickly unfolding military air and space operations and capable of supporting deliberate intelligence operations. The Air Force should examine the National Reconnaissance Office's experience in operating taskable space systems that must meet both standing and ad hoc requirements.

The organizational structure of theater command and control centers may have to be expanded to include an authority responsible for space systems. That authority might be a space component commander who, like the air component commander, reports directly to the joint task force commander; or it might be a space coordinating authority under the air commander. The latter option may be sufficient until operational or tactical control of selected space forces (e.g., taskable, multimission assets) is delegated to regional UCCs or theater-deployable space capabilities are developed.

To ensure optimal employment of new space systems in joint operations, a well-trained space cadre should be developed within the Air Force to provide a pool of knowledgeable persons for assignment to space-related theater and rear support positions.

Because the space-based radar will serve the intelligence community as well as DoD, the utility analyses now under way for that system should not be restricted to military missions. The breadth of the analyses will reflect on the breadth of the perspective the Air Force is viewed as taking in its new role as DoD Executive Agent for Space.

If space systems such as SBIRS are to be effectively integrated into mission architectures and operations plans for new weapon systems, integration should ideally start early in weapon system development. One option is to require the development of space support plans for future weapon systems, possibly using intelligence support plans as a model. Another is to include interoperability

requirements during the development of operational plans and architectures for missions such as theater missile defense.

### **Integrating National Space Assets Is a Further Hurdle**

Theater operations have been integrated with national space assets in the sense that the regional UCCs have reported ISR needs to the intelligence community, which has established space-asset tasking priorities. In shooting wars, requests from the theater have usually been given high priority; and collected information has been transmitted to the regional UCC through a range of reports, imagery, and maps.

Although such a process has been well suited for deliberate planning, it has not worked as effectively in other operations. For example, current ISR capabilities have been limited in their ability to support operations against such time-critical targets as highly lethal and mobile theater ballistic missile launchers and air defense systems.

Integrating air and space ISR (including national assets) to support air operations against time-critical targets requires the collaboration of multiple organizations (the military services, joint-service organizations, and the intelligence community) and goes beyond space-air C2BM integration. Neither the Air Force's air community nor its space community, individually or together, can address the range of ISR integration challenges. Moreover, the Air Force has not yet had to manage taskable, multimission space assets. It thus appears prudent for the Air Force to wait until it acquires experience with near-future DoD space systems having similar capabilities before confronting the greater challenge of integrating the C2BM of national space-based and airborne ISR systems. Meanwhile, the Air Force might benefit from mapping its space-air ISR C2BM initiatives to the components of the DoD's *ISR Integrated Capstone Strategic Plan*.

MR-1521-AF, *Integration of Air and Space: Focus on Command and Control*,  
Myron Hura, Gary McLeod, Jody Jacobs, Richard Mesic,  
Manuel Cohen, Philip Sauer

## Absorbing Air Force Fighter Pilots: Parameters, Problems, and Policy Options

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The Air Force is confronted by a difficult aircrew management challenge. Current rates of producing and retaining fighter pilots are too low, and training capacities in operational fighter units are insufficient to prepare the influx of inexperienced pilots.

In response to this dilemma, and as part of ongoing research into training shortfalls, PAF researchers examined key factors affecting the Air Force's ability to provide training and experience for new pilots in operational fighter units, and they identified possible policy options to address the growing aircrew management crisis.

### Force Structure Cuts and High Workloads Set the Stage

The Air Force experienced both substantial cuts in force structure and new demands for its services during the 1990s. While workloads rose for the shrinking number of operational fighter units, training resources dwindled. At the same time, retention rates fell; and, in spite of overall manning shortages, an excess of new pilots accumulated in the already overburdened operational units. The result is a growing crisis in the Air Force's capacity to train and incorporate—i.e., to *absorb*—new fighter pilots.

### Overtaxed Training Resources Inhibit Absorption

New fighter pilots must first be assigned to operational units and fly under supervision as they develop the expertise and mission experience essential to subsequent assignments. Crucial to the development of new pilots is an adequate quantity and appropriate mix of training experiences drawn from a full range of mission profiles. If these opportunities are unavailable, the negative consequences are immediate. For example, at a base suffering from a severely degraded training environment, almost 90 percent of the supervisors and instructor pilots interviewed in August 2000 said that wingmen in their units were flying advanced missions “without a fundamental foundation in certain basic skills.” When they receive such limited training, new pilots find it difficult to *maintain* their perishable flying skills, much less develop new ones.

If operational units cannot accommodate the influx of new pilots, the dangers are considerable. The immediate result is a diluted and deteriorating training environment that can quickly generate the larger and more threatening problem of diminished readiness and combat capability. Moreover, a long-term shortfall arises in the cohort of new pilots, who miss irreplaceable opportunities to develop fundamental skills, knowledge, and capabilities and whose credibility and effectiveness are diminished in subsequent staff and leadership positions. The Air Force thus must find a way to increase its inventory of pilots while ensuring that training environments, already strained, can accommodate the new members.

### New Models Assess the Capacity to Absorb New Pilots

To investigate the abilities of operational units to absorb new pilots, PAF researchers developed the first models capable of accurately calculating the effects of reduced experience levels and overmanning on *absorption capacity*—the maximum number of pilots each year who cross established experience thresholds. The key elements that determine a unit's absorption capacity are its *training capacity*, essentially the number of sorties the unit can devote to training, and the *aging rate* of its new pilots, the rate at which new pilots accumulate experience. This parameter responds adversely to increased manning at reduced experience levels. The models thus incorporate the degradation that results when units take in more new pilots than their training capacity and aging rates can accommodate.

### The Double Bind Requires Urgent Solutions

Using these models and a best-case scenario, the research team determined that, even under highly optimistic conditions in terms of force structure availability and training capabilities, Air Force operational units can absorb only 302 new fighter pilots each year—far short of the Air Force's current goal of 330 per year. More daunting still, given current retention figures, the Air Force actually needs to produce and absorb more than 380 new fighter pilots each year to fill its requirements for experienced officers.

The Air Force faces a double bind: Its current production goal is too high for the existing force structure to absorb but too small to fill future demands. The need to enhance the capacity of units to absorb new pilots successfully and efficiently has never been clearer.

## Manning and Training Changes Are Underway

The Air Force is examining several possible solutions, particularly some that would create units that include pilots from both active and reserve components. One example is an *active associate* program that incorporates active pilots in reserve units and *blended units* that contain active, guard, reserve, and/or civilian members, depending on specific unit needs. Operational guard and reserve units have collective experience levels near 90 percent, while experienced fighter pilots are in short supply in the active force. The advantages of shifting some of the requirements for experienced pilots to the reserve components are apparent.

The Air Force is also investigating methods for increasing training capacity, including increasing the number of training sorties to provide more opportunities for new pilots to gain experience. Other options include placing more fighters in the active component, improving the distribution of available sorties, extending the duration of sorties and operational tours, and lowering experience standards. All warrant careful assessment because each brings its own risks in terms of diluting experience levels and thus combat readiness.

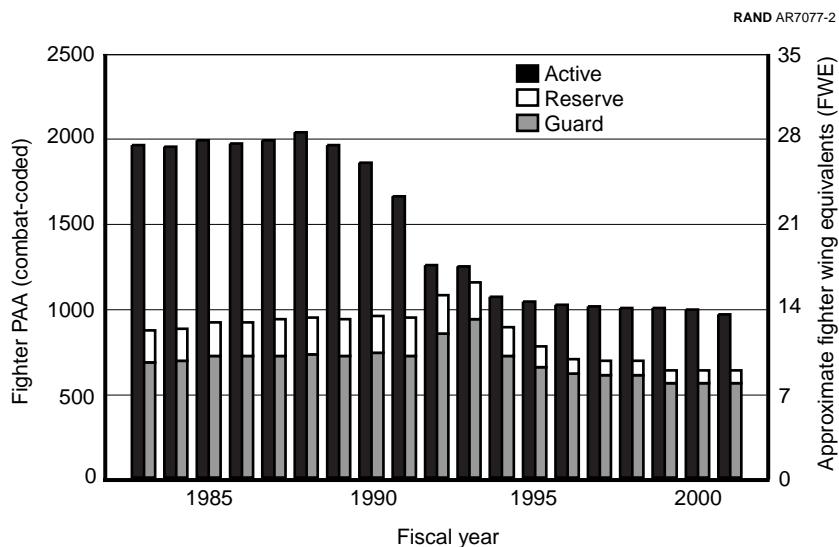
Finally, the Air Force continues to try to reduce its requirements for experienced active-component fighter pilots in organizations other than operational wings. For example, many staff jobs have been turned over to civilians (usually former fighter pilots) and other categories of officers. In addition, the guard and reserve have taken larger shares of the workloads for so-called undergraduate pilot training and initial fighter training (before new pilots go to operational units).

## Expanding Aircraft Availability Is Crucial

These manning and training options offer the potential to make some headway toward resolving the absorption crisis, but none provides a full or lasting solution. The options are simply not sweeping enough to make significant progress toward a goal of 100 percent manning and 60 percent experience levels for operational units—levels the researchers targeted as permitting inexperienced pilots to fly roughly the same number of sorties as experienced ones.

The only initiatives that can permanently resolve Air Force fighter pilot absorption issues are those that address the downward trend in primary aircraft authorizations (PAA), illustrated in Figure 2. Regardless of its other components, any policy program must feature an increase in PAA. If sizable PAA augmentation is not feasible, more innovative uses of the total force will be necessary. Three principal options exist for dealing with PAA shortfalls:

- Increase active PAA directly by adding new units or increasing PAA authorizations in existing units.
- Increase active PAA indirectly by reorganizing active units to improve absorption capacity. This option likely necessitates closing some units to increase the capabilities of those remaining.
- Increase PAA virtually by making more creative use of the force structure. The active associate or blended units already being tested, for example, could enable the existing PAA to absorb new pilots much more efficiently than using the active assets alone.



NOTE: All aircraft authorizations for operational units are combat-coded. An approximation of the corresponding changes in FWEs is given on the right-hand axis. These numbers are approximate because they include small numbers of aircraft (such as OA-10s or air defense force-tasked units) that are not usually included in FWE calculations. Small numbers of nonabsorbable aircraft (such as F-117s) are also included. Data are from the Air Staff (AF/XPPE).

**Figure 2—Active Fighter PAA Reductions Are Central to Current Absorption Problems**

However, all three options have serious budgetary and policy implications, and the third option will test traditional culture in the Air Force fighter community.

Despite such hurdles, these long-term policy options merit immediate and thorough analysis, as do possible adjustments in retention or pilot requirements. The potential outcomes of such options must be compared to the problems that will arise if no action is taken and operational units continue toward the problematic conditions associated with the excessive inflow of new pilots.

## A Dynamic System Requires a Delicate Hand

No single policy alternative can resolve this multifaceted and complex crisis. Instead, the research findings demonstrate the degree of care necessary to manage the delicate balance among manning, assignment sequences, training tempo, and training allocation in order to forestall the inadequate development of future generations of pilots. Small alterations in any of these factors can have ripple effects, dramatically changing the entire system.

Currently, however, no means exist by which to evaluate in a dynamic way the intricate, interrelated elements affecting absorption and the array of policy options available to improve absorption rates. The researchers thus recommend the development of such a means—specifically, a dynamic modeling framework, coupled with a comprehensive longitudinal database of the kind the researchers developed and used to document indicators of training problems for the current research. This kind of modeling environment could provide the near-real-time indicators that decisionmakers need to confront manning and training issues and develop viable long-term solutions.

A systematic analysis of the available options, beginning with increased PAA and extending through more creative uses of force structure, should help decision-makers determine the most effective policies to manage the current dangers and meet future needs.

MR-1550-AF, *Absorbing Air Force Fighter Pilots: Parameters, Problems, and Policy Options*, William W. Taylor, James H. Bigelow, S. Craig Moore, Leslie Wickman, Brent Thomas, Richard Marken

## Air Force Compensation: Considering Some Options for Change

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In the 1990s, the Air Force faced a manpower crisis, both in terms of declining recruitment and retention and a drop in "high-quality" recruits.<sup>2</sup> The crisis passed with the softening of the economy, an increase in recruiting resources, and military pay raises. The experience, however, led the Air Force to determine that it needed to look more closely at its compensation system in order to remain competitive with civilian opportunities, prepare for future downturns, maintain or increase retention rates, and continue to attract skilled personnel. The Air Force Chief of Staff asked PAF researchers to examine its current pay system and to provide an initial assessment of two potential alternatives: skill pay and capability pay.

### Manpower Crises: Can the Current Pay System Measure Up?

At the most basic level, to compete with civilian pay the Air Force needs to develop the capability to monitor and analyze civilian wages more closely and with minimal lag. The Air Force's challenges in the 1990s were due in no small part to the strong civilian economy, which offered abundant prospects and climbing wages. Today's flagging job market, however, has not ended the Air Force's competition with civilian opportunities. Further, the long-term upward trend in college enrollment, which tends to reduce the Air Force recruitment pool, remains a challenge. In fact, the manpower crisis served to emphasize the larger issue of whether the Air Force pay system can continue to meet its recruitment and retention goals in the face of future deployment demands. Two related questions emerged from the crisis: Can the Air Force improve its pay to meet its manpower needs? Does the pay system offer enough flexibility to ensure that the best and brightest are drawn to the service and, once there, are not lured away, especially in key specialties and for future leadership roles?

### New Pay Systems Merit Further Investigation

A primary draw of the civilian market is that it offers variations in pay based on factors such as ability, knowledge, and skill level; and it shows no reticence about

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<sup>2</sup>High-quality recruits are those with a high school diploma and a score in the upper half of the Armed Forces Qualification Test score distribution as normed in 1980.

paying different skills differently, thus serving as an enticement for talented individuals. However, the Air Force, along with the other military services, operates under a single basic pay table and pay raises derive from promotions. Although promotions are obviously influenced by skill and ability and although bonuses provide some “equalizing differences,” there is still less pay variation than in the civilian market.

Implementing new pay components—skill pay and capability pay—is one way of providing the salary variation that the civilian market offers. This approach offers incentives to attract and retain personnel as well as a means by which to draw out those most capable and ensure their path to leadership positions.

Skill pay provides compensation for demonstrated skill attainment. Such pay is designed to help conserve a supply of individuals who have skills that are valuable for military capability and who may be expensive and difficult to replace. This pay would also serve as an attractive incentive for acquiring and maintaining essential skills. In the long term, skill pay would contribute to a desirable variance in career pay profiles across specialties and within retention profiles and career lengths. To implement skill pay, the Air Force would need to identify and define which skills it seeks to reward, establish a program to certify that individuals have maintained their skills, and determine how the pay should be implemented (e.g., in a flat amount or as a percentage of basic pay, with the percentage rising with rank and years of service). Among its limitations, however, is the fact that, once set up, skill pay would need to remain fairly static or be amended only gradually to avoid looking unpredictable and capricious. On the other hand, if too rigid, such pay cannot respond to new technologies that modify the value of skills and introduce new skill areas.

Capability pay grants compensation for exemplary individual capability, especially leadership potential. This pay is designed to help retain the most capable personnel while providing them with an incentive to qualify. As with skill pay, capability pay would result in greater pay differentiation within each rank and year of service. Once again, of course, such pay would require developing a means of assessing capability in a way that is perceived to be both standardized and fair. Implementation possibilities include payment in a smaller increment over the remaining years of service or as a larger increment over a shorter period. It could also be skewed to rise with rank, year of service, and past levels of capability attained. Problems with the system, however, include the danger of misclassifying personnel as high or low performers or functioning as a disincentive to personnel who do not qualify and thus leave the service under the assumption that their career prospects are limited. The threat to morale and productivity that may come from a system that rewards only certain personnel is a significant limitation.

This research provides only the first step in looking at both payment components, raising the issues that future investigations need to consider. The researchers recommend further work into the implementation possibilities, costs, and effects of these kinds of pay—for example, through developing policy simulations to see whether high-ability personnel are more likely to be retained under certain pay structures and through conducting focus groups and surveys to determine whether personnel would be receptive to these pay models and in what form.

### **Changes in the Current System May Be a Feasible Alternative**

The outcomes promised by these new components may in fact be achievable by implementing strategic but comparatively modest changes in the current system to make it more responsive to the Air Force's evolving needs. Instituting a pay policy that builds on the existing compensation system rather than on entirely new types of pay may be desirable for several reasons. First, the system has been in place since 1948, and service members and policymakers seem reluctant to change it because it has weathered a variety of historical transitions in the last half-century. Further, while criticized for its one-size-fits-all pay table and thus its limited flexibility, the current system seems resilient enough to withstand alterations that may go a long way toward ameliorating the manpower crisis.

Thus, the research team targeted a series of promising changes in the current system:

- *Restructure the promotion timetable to promote personnel more quickly.* Advancing promotion by two years, for instance, would offer pay increases in the short and long run and would likely enhance retention rates. But such a change has disadvantages, too. For instance, if applied uniformly, promotions would occur in specialties with no retention problems. If administered selectively, however, it would represent a departure from the long-held Air Force policy of equal promotion opportunity, regardless of specialty.
- *Increase the value of selective reenlistment bonuses, and tie these bonuses more directly to skill level and grade.* This change, like skill pay, would create greater incentives to reach higher skill levels. These bonuses would also enable more-variable career lengths and a greater “experience mix” across skill areas. Many of the benefits of skill pay would thus be integrated into the current pay table without having to overhaul the system. There are downsides, however, such as the fact that bonuses tied to skill may again conflict with the Air Force’s policy of equal opportunity.

- *Provide better recognition for hostile duty.* At present, personnel receive a flat \$150 per month for any hostile duty or exposure to imminent danger. This pay could be altered to reflect the number of hostile episodes encountered. Pay could thus be scaled so that the more past hostile episodes experienced, the steeper the pay increase for the current episode. Such an adjustment should help curb lower reenlistment and may encourage reenlistment among those who are most called upon for hostile duty.
- *Restructure the pay table.* Finally, a more far-reaching change deserves further investigation: reshaping the current pay table so that promotion pay raises increase with each successive promotion. By “skewing” the pay table to have pay rise more rapidly with rank, the Air Force may be able to increase retention rates, boost performance incentives, and encourage the retention of the most capable personnel. Many of the benefits of capability pay would thus be achieved but in a less sweeping and conceivably more cost-effective way.

These changes merit further investigation because they have the potential to enhance the Air Force’s compensation flexibility while also helping to retain and motivate high-capability members, providing incentives for acquiring skills, and ultimately creating careers of different expected lengths.

### **It May Be Time to Reevaluate the Golden Handcuffs**

More radical than significant adjustments to the longstanding pay system is the idea of altering a component that is deeply ingrained in all the military services: the retirement system. Because the Air Force’s retirement policy is arguably the largest impediment to flexibility in force management, looking into such a change may be called for. Regardless of occupational area, the system locks mid-career personnel in “golden handcuffs” until their twentieth year of service, at which time it gives them an incentive to leave and begin collecting benefits. Past studies have recommended a restructured system that would vest retirement pay earlier and operate as a thrift savings plan with both the member and the government contributing. These studies also suggest putting a larger fraction of compensation into basic pay and bonuses—a welcome change for younger personnel and a cost-effective one for the government. In light of these findings and the recent manpower crises, a reevaluation of the retirement policy may be warranted.

## A Flexible and Responsive System Will Ensure That Future Manning Goals Are Met

Obviously, all of these changes have disadvantages, and the road to implementing any of them may be rocky in terms of their impact on Air Force culture, which has operated with relative stability in compensation for over fifty years. All of the services, however, have begun to recognize the value of having longer careers in particular specialties and keeping a reserve of personnel in certain positions for a longer time. Moreover, as competition with the civilian workforce increases and as the needs of the Air Force evolve, the potential rewards of changes to the compensation system and the possible introduction of components such as skill and capability pay are too great to ignore. The Air Force needs to be as responsive as possible in the face of global, national, technological, and internal contingencies. A flexible compensation system will be a critical tool in achieving that goal.

MR-1566-1-AF, *Air Force Compensation: Considering Some Options for Change*, James Hosek, Beth Asch

## Improving Air Capabilities Against Time Critical Targets: Lessons from Recent Operations

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In air operations in Southwest Asia and the Balkans during the 1990s, the United States proved the effectiveness of its strike and interdiction capabilities against fixed targets and stationary force elements. As a result, adversaries responded by increasing their use of mobile and concealed forces. Requiring immediate response from U.S. forces, these time critical targets (TCTs) call for a dynamic system of operations that differs substantially from the preplanned forces used against fixed targets.<sup>3</sup> This system of operations, known as dynamic command and control and battle management (DC2BM), determines the ability of U.S. forces to monitor, assess, plan, and execute air operations within a short timeframe.<sup>4</sup>

In light of the limited effectiveness of U.S. air missions against TCTs in conflicts during the last decade, PAF researchers examined recent operations to help the Air Force enhance the DC2BM of air assets in operations against TCTs. They recommend comprehensive improvements in procedures, detection, automation, and networking to better performance across all missions involving TCTs.

### Recent Experience Highlights Shortfalls in Four Mission Areas

Based on a review of Operations Desert Storm, Southern Watch, Northern Watch, and Allied Force, the researchers identified four key mission areas in which DC2BM had produced disappointing results: counter-air operations, theater missile defense, suppression of enemy air defenses, and interdiction.

#### ***Counter-Air Operations Require a More Accurate Air Picture and Quick, Secure Digital Communications***

The U.S. Air Force is well prepared for counter-air operations against conventional military aircraft; however, the nature of counter-air operations is chang-

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<sup>3</sup>TCTs can be defined as fleeting targets of opportunity that pose a danger to friendly forces and require immediate attack. This category of targets includes aircraft, cruise and ballistic missiles, air defenses, and small-unit ground forces.

<sup>4</sup>DC2BM refers to the systems and capabilities required to receive and rapidly integrate information from multiple sources, use this information to select targets and pair them with weapons, disseminate decisions and attack orders rapidly, and assess the effects of those attacks.

ing. Minimizing friendly losses and collateral damage is becoming an imperative. In Operation Allied Force, it was difficult to conduct effective and efficient air-to-air engagements in a crowded air space that contained coalition aircraft (both conventional and stealthy) and enemy aircraft. A major problem was commanders' inability to determine quickly whether an air target was friendly or hostile. Without access to an accurate air picture, commanders rely on restrictive rules of engagement to minimize the chance of fratricide and collateral damage, which can result in lost opportunities to engage the enemy or permit the enemy to gain an advantage while the United States delays its response.

In the near future, the air picture will become more complex as adversaries begin using low observable cruise missiles and the Air Force increases its own use of unmanned aerial vehicles for reconnaissance and possibly strike. U.S. air commanders must then be able to assess quickly and accurately whether a target is hostile, friendly, or neutral. Upgrading the Airborne Warning and Control System, for example, will improve target tracking and identification, and it will reduce response times in battle.

To improve counter-air operations, the Air Force should also increase its network of tactical data systems. In battle, weapons directors must relay timely and accurate threat data to airborne interceptors. Using a digital communications network rather than voice messaging will enable faster and more reliable data transmission, and it will use only a fraction of the communications resources of interactive voice messaging. While the Air Force has equipped its ground command and control centers and some of its fighters with tactical digital communications networks such as Link 16, DC2BM capabilities will improve with more extensive use of data networks that support near-real-time information exchange.

***Theater Missile Defense Demands Better Target Detection, Decision Tools, and Automated Data Management***

The allies' disappointing performance against Iraqi mobile Scud theater ballistic missiles (TBMs) in Operation Desert Storm shows that current command and control capabilities are inadequate against TBMs and their launchers. These launchers are particularly important TCTs because destroying them can stop further missile reloads. To respond adequately to this type of threat, the Air Force must streamline its command and control functions so that the time from initial detection of a possible target to strike order issuance approaches 10 minutes or less.

Because of the distance and flexibility associated with long-range TBM threats, the Air Force will need new sensors capable of detecting targets reliably in deep-look, long-dwell-time, all-weather/day-night operations. Similarly, sensor upgrades for

fighters will help them track, identify, and target TCTs more accurately and allow them to engage these targets under difficult battle conditions.

In addition to better target detection, theater missile defense in future conflicts will require more responsive, rationalized decisionmaking by combat planning staffs. The speedy analysis of action/reaction cycles (based on the principles of game theory, for example) is critical to determining the most profitable strategies in combat.

For better target detection and more successful decisionmaking regarding potential TBM threats within a timeframe of 10 minutes or less, the Air Force should develop a robust collaborative environment built around a high-speed computer network, automated data transmission, and an expert, empowered information manager. This on-demand collaboration and communications network will enable commanders to perform more effectively against the mobile TBM threat.

***Suppression of Enemy Air Defenses (SEAD) Calls for Improved Threat Detection, Faster Decisionmaking, Networked Communications, and New Weapons***

SEAD is an especially important mission area because its success or failure can affect all air operations and ground operations that depend on air support. SEAD has two direct objectives: to minimize the loss of friendly aircraft and to maximize air power flexibility and effectiveness. SEAD is resource intensive, requiring significant allocations of both aircraft and personnel.

In military operations during the 1990s, the U.S. military could not adequately detect, locate, identify, track, and target antiaircraft artillery and man-portable surface-to-air weapons, thus restricting the use of low-level-flight operations. SEAD will become even more challenging in the future if, as expected, adversaries deploy more sophisticated air defense systems with increased range, lethality, mobility, and integration.

Situational awareness is critical when facing adversaries with advanced air defenses. Like theater missile defense, SEAD requires long-dwell-time sensors that will operate reliably day and night in unfavorable physical conditions. Without the ability to accurately detect these threats in a wide range of environmental conditions, U.S. military forces cannot perform successfully against them.

Meeting the challenge of adversaries' expected advances in air defenses will demand that the Air Force deploy SEAD weapons with increased stealth, range, and lethality. The effective use of such weapons will call for enhanced DC2BM capabilities to cue and rapidly retarget them in combat. As with other mission

areas, suppression of an enemy's advanced air defenses will rely on extensive data networks that enable the information transfer and quick decisionmaking required to engage TCTs.

***Interdiction of Small-Unit Ground Forces Requires Integrated Air and Ground Information, Decision Aids, and New Operational Concepts***

Interdiction operations shape the battlefield, destroy hostile ground forces, and disrupt enemy lines of communication and logistics support. Because of the nature of warfare prior to 1991, the Air Force focused on the interdiction of large armor formations and devoted fewer resources to air-to-ground engagements against small-unit ground forces. However, operations in the last decade have demanded greater capabilities against small ground forces, especially those intermingled with the civilian population. In Operation Allied Force, for example, interdiction of small ground forces was poor because the Air Force had difficulty identifying potential targets and assessing collateral damage.

Identifying military forces that are intermingled with civilians is a difficult process that should involve joint-service efforts. Because it depends more heavily on ground sensors than air sensors, the Army and special operations forces should participate in assembling an integrated picture of air and ground threats. Like other types of missions, interdiction of ground forces will need an improved information network, one that will enable smooth coordination between land and air commanders. To facilitate this coordination, the Air Force should also establish new operational concepts to support better communication between the land and air forces.

Like the other mission areas, interdiction against small ground forces requires prompt target assessment and rapid decisionmaking. Future interdiction operations will benefit from decision tools that help commanders assess the situation, recommend response options, determine collateral damage, and support a go/no-go decision.

**Four Top-Level Initiatives Will Increase Overall Effectiveness Against TCTs**

Four comprehensive improvements will allow the Air Force to enhance performance against TCTs across different types of missions. To address the evolving DC2BM needs, the researchers recommend that the Air Force take the following top-level actions:

- Refine operational concepts and procedures to clarify where and how DC2BM functions should be performed and by whom.
- Establish systems that provide a common view of the battlespace.
- Increase automation to reduce the time from target detection to weapons on target.
- Develop a robust computer network to support the rapid collaboration and communication needed for assured decisionmaking in a short period of time.

In developing a flexible approach to TCTs, the Air Force must ensure that none of the innovations jeopardizes capabilities to execute preplanned missions against fixed targets, which will remain a crucial component of air power. It will be important to seek out joint-service solutions for all mission areas, particularly against small ground forces and theater air and missile threats. The Air Force should also take action to ensure that the enhancements to DC2BM are adequately funded and synchronized with those in aircraft, weapons, and intelligence, surveillance, and reconnaissance. The resulting DC2BM system should respond effectively to current enemy threats and remain flexible to meet the demands of the future.

MR-1496-AF, *Enhancing Dynamic Command and Control of Air Operations Against Time Critical Targets*, Myron Hura, Gary McLeod, Richard Mesic, Philip Sauer, Jody Jacobs, Daniel Norton, Thomas Hamilton

## The Stryker Brigade Combat Team: Rethinking Strategic Responsiveness and Assessing Deployment Options

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Historically, the United States has been unable to deploy large joint forces globally within a short timeframe of days or weeks. If the Army's current efforts to transform its rapid-response power are successful, however, such deployment capability will finally be within reach.

Given the extent of the Army's planned transformation, PAF considered its broader implications in terms of Air Force operations and force structure. The research team sought to determine whether the Army's deployment goals can in fact be met with existing bases and airlift and sealift capabilities.

### **The Army Plans New Rapid-Response Teams**

The Army's transformation is driven by a desire to bridge the gap between its heavy warfighting forces, which are difficult to deploy, and its agile rapid-response forces, which lack staying power against hulking, mechanized forces. The Army's solution is the inauguration of Stryker Brigade Combat Teams (SBCTs),<sup>5</sup> an interim force of medium-sized teams equipped with medium-weight armored vehicles. The SBCTs will have more firepower than light infantry but will be easier to transport than heavy armored forces. The goal is to develop the capacity to deploy these teams anywhere in the world within 96 hours after liftoff. The SBCTs mark the first step toward the larger ambition of developing an Objective Force able to place a combat-capable brigade anywhere in the world in four days, a division a day later, and five divisions within a month.

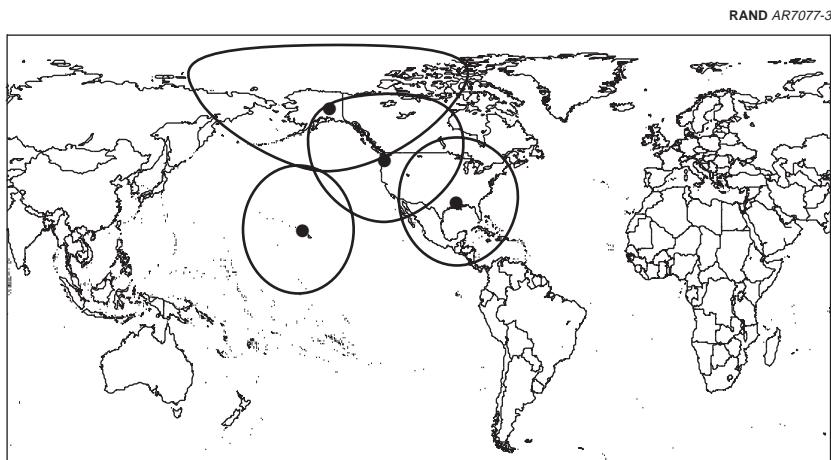
### **A 96-Hour Goal Is Currently Unreachable**

Ultimately, the PAF team concluded that moving a Stryker Brigade's nearly 13,000 short tons of equipment and 3,500 troops, in addition to 2,500 tons of supplies, 900 tons of airlift equipment, and roughly 1,000 airlift personnel, in 96 hours

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<sup>5</sup>The SBCT is named after two congressional Medal of Honor winners: Private First Class Stuart S. Stryker, WWII; and Specialist Fourth Class Robert F. Stryker, Vietnam.

would require loading and launching four C-17 airlifters per hour for nearly the entire four days. This rate would mark a staggering achievement under the best of circumstances and remains unlikely in the face of the airport infrastructure constraints in much of the world. Moreover, even if these deployment rates could be managed, the maximum distances that could be reached from the projected SBCT bases are limited, as Figure 3 shows.

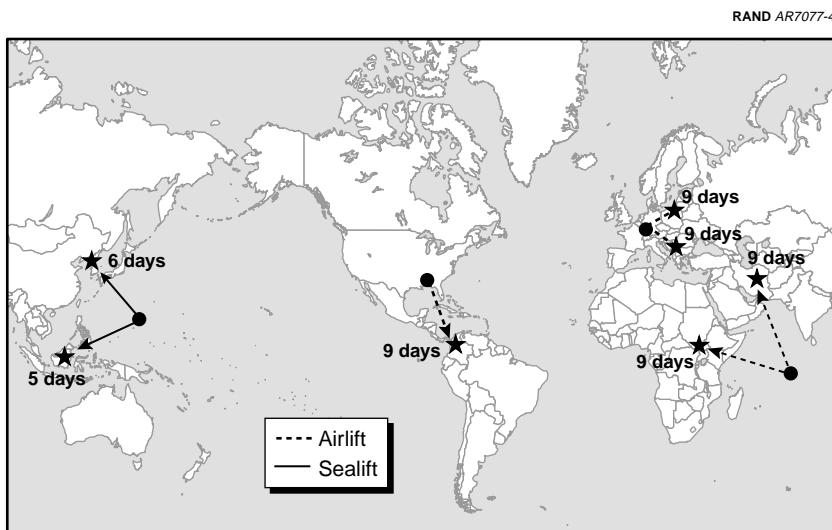


**Figure 3—SBCT 96-Hour Reach from Hawaii, Alaska, Washington, and Louisiana**

The promising findings, however, are that a combination of U.S. bases, a forward-based SBCT in Germany, and regional prepositioned sites in Guam and Diego Garcia would allow the United States to deploy the SBCTs by air or sea to key regions in 5 to 14 days—a great improvement on past deployment options. Figure 4 illustrates the various deployment times to strategic areas from these basing locations.

### **Sealift Versus Airlift Considerations Affect Deployment Speed**

Even if obstacles still stand in the way of the 96-hour goal, specific deployment and basing options could help maximize the responsiveness of the new SBCT. Pivotal to any deployment decision is the choice of sealift or airlift, each with its own constraints. For instance, weight is a key factor in airlift, while port capacities and availability affect sealift deployment options. As might be expected, coastal operations generally favor sealift, and operations far into the landmass favor airlift.



**Figure 4—Regional Basing, Showing Rapid Deployment Times to Key Areas**

To evaluate the deployment times for a medium-weight Army brigade like the SBCT, PAF researchers analyzed three representative scenarios—in Kosovo, Rwanda, and Indonesia. In both the Kosovo and Indonesia scenarios, the SBCT arrived faster by sea than by air, given the use of fast shallow-draft ships, which have the benefit of faster transit time and the ability to access small ports without the time-consuming use of transport barges. The Rwanda scenario, however, shows the value of airlift for operations farther into landmass interiors.

### Prepositioning Proves Most Effective at Speeding Deployment

Beyond questions of sea versus airlift, the capability to deploy from regional bases rather than from the continental United States is central to expediting response. In all three scenarios, SBCT equipment sets or the units themselves would need to be forward-deployed to achieve response times of under ten days. In fact, the prepositioning of equipment or overseas basing of forces is the single most effective way to accelerate SBCT deployment.

## Strategic Responsiveness Emerges as a Key Concern

Because the SBCT has the potential to accelerate deployment times significantly, the question emerges as to how these forces may be used strategically. That is, are there current or future political-military conditions that might profit from or even necessitate such a *strategically* responsive force?

Historically, the United States has had minimal need for rapid deployment of large joint forces, both because of the concentration of large U.S. joint operations in relatively few regions (Europe, Latin America, the Persian Gulf, and Asia) and because the nation has seldom been surprised by events requiring exceptionally rapid deployments. In fact, deployment generally follows months or more of deliberating over combat operation alternatives, weighing the threat to national interests, and considering the risks of U.S. casualties. Such timelines have the advantage of allowing for valuable prepositioning of equipment and overseas basing.

## The Nation Will Benefit from Rapid-Response Enhancement

Despite long deployment timelines in the past, rapid deployment capabilities are still desirable. Often, the more quickly action is taken, the greater the chance of reducing human suffering, as in the case of genocide, or minimizing political complications, as in the case of conflicts necessitating unwieldy coalitions.

Of the regions where the United States is likely to operate in the next few years—Central America and the Caribbean, the NATO-Alliance area, the Balkans, the Middle East, and Southwest Asia—two are reasonably easy to reach. The Caribbean is within a few hours' flying time, and even Colombia can be reached without aerial refueling. In turn, the NATO-Alliance area has a well-developed infrastructure and the United States maintains heavy and light ground forces in Europe. On the other hand, the Middle East and Southwest Asia—in addition to possible “hot spots” in East Asia and the Pacific Rim—present major access challenges that could be ameliorated by greater deployment flexibility. Much in the way of strategic responsiveness could be gained if the United States devoted more attention to these regions, including preparing regional bases during peacetime to act as power-projection launching points for rapid-response teams.

## Terrorism Is the “Wild Card” in Predicting Deployment Needs

Unlike these easily identifiable “hot spots,” future terrorist threats are much less knowable. Given mounting dangers, the United States may need to use military force on short notice and in unexpected locations. Al Qaeda, for instance, might operate clandestinely in virtually any location, possibly under the cloak of other groups or insurgent movements. Terrorism will likely prove enough of an escalating challenge that the United States would benefit from greater rapid-deployment capabilities. For such operations, the U.S. forces involved are more likely to be smaller than the SBCTs and even more easily deployable. However, the nature of deployments that may be triggered by terrorism is still difficult to forecast, making any improvements in response time potentially beneficial.

## The Air Force and the Army Have Begun a Dialogue on Ways to Improve Deployment Flexibility

Because of these uncertainties and the growing potential to substantially reduce deployment time through prepositioning, tactical basing, and other strategic efforts, the Air Force should support the Army’s transformation. The development of medium-weight forces promises capabilities that are unattainable in current light or heavy forces. Although the ambitious 96-hour deployment objective may not be feasible, air transport remains the fastest option for many contingencies. Sealift may be preferable for coastline operations, but even in these cases airlift is still likely to be called upon for critical personnel and equipment.

The Air Force thus has a clear stake in the Army’s transformation because it will require that future forces operate in closer air-ground cooperation on intelligence, surveillance, lift, and precision fires. The Army would benefit from the Air Force’s expertise in air deployment, reconnaissance, survivability of transport aircraft, and air-to-ground fires. Conversely, as it develops new concepts for air-to-ground operations, the Air Force would benefit from the Army’s expertise in land operations and future battlefield technology. A dialogue between the Air Force and the Army is already underway and is expected to encourage the development of new concepts for air and mobility that will further enhance future U.S. deployment flexibility.

MR-1606-AF, *The Stryker Brigade Combat Team: Rethinking Strategic Responsiveness and Assessing Deployment Options*, Alan Vick, David Orletsky, Bruce Pirnie, Seth Jones

## **Effects-Based Operations: A Grand Challenge for the Analytical Community**

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In addition to targeting military forces, commanders in the field often consider how their actions affect an enemy's decisionmaking ability, intelligence, and morale and how these effects can be used to achieve operational goals more efficiently. For example, a commander might select a specific course of action based on the probability that enemy troops will become demoralized and will be slow to respond. In cases such as this, current methods of operational planning and analysis do not help commanders to see the full range of options available to them. Effects-based operations (EBO) are difficult to represent in models because they involve qualitative factors such as thought and behavior and because they are based upon probable outcomes. As a result, analysts often ignore them in favor of more tangible factors such as weapons capability, troop size and speed, and the military force necessary to ensure victory under worst-case conditions.

In recent years, however, U.S. military planners have become increasingly interested in EBO. This movement responds to warfighters' demands that modeling and analysis become more relevant by taking into account the full scope of realities in the field. It also responds to the military's overall interest in rethinking the art and science of war since the 1991 Gulf War. EBO presents the analytical community with an opportunity and a grand challenge to change the current mind-set, to develop new theories and methods, and to build a new empirical base for models.

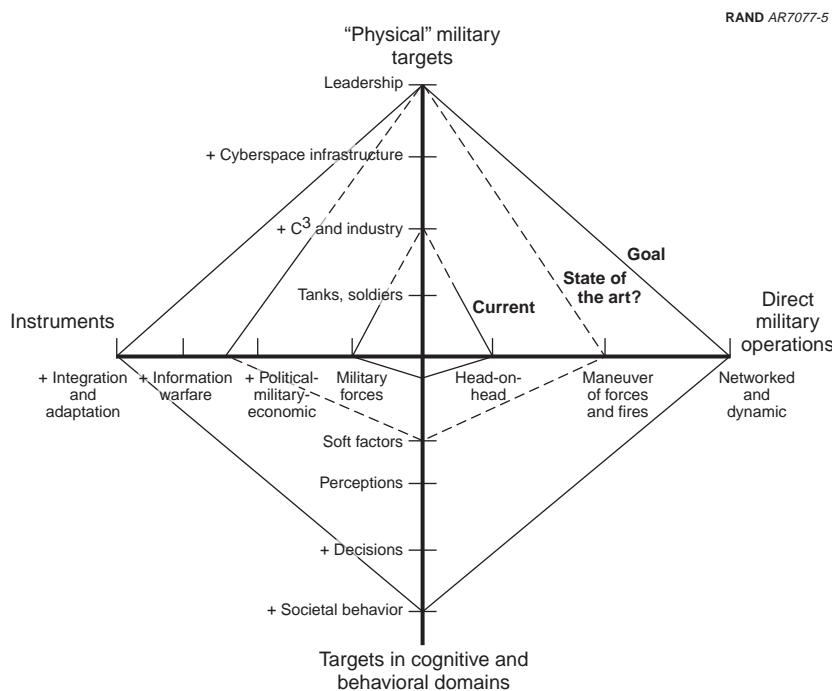
This study introduces principles for integrating EBO into defense-planning analysis. It determines that a broader, more reality-based approach to modeling could provide warfighters with better tools for conducting their operations. Finally, the study suggests a program of further research to improve the empirical base for EBO models.

### **EBO Extends, But Does Not Replace, Traditional Practices**

The analytical community has resisted the concept of effects-based analysis for many years. A major reason for its resistance is that EBO analysis has not been well defined, particularly as it relates to traditional types of defense analysis.

Skeptics wrongly assume that EBO seeks to replace classical warfighting instruments such as destruction or attrition of enemy forces and occupation of territory with more mysterious objectives such as creating shock and awe and attacking an enemy's conceptual centers of gravity.

On the contrary, it must be understood that EBO extends the scope of warfighting instruments and targets and provides commanders with greater options and flexibility on the battlefield. Figure 5 illustrates the scope of effects-based planning in comparison with current analysis. The small, nearly triangular shape in the center represents current practice, which focuses on the employment of military forces for head-on-head attrition and generally targets an enemy's physical forces. Very little effort is made to plan for attacks on an enemy's thinking and behavior. As the large diamond shows, the goal of EBO analysis is to push the frontiers outward in all four directions, using the full range of military, diplomatic, psychological, and economic instruments both to attack military targets and to impact enemy thinking and behavior.



NOTE: The axis of physical targets relates to both direct physical and systemic effects; dashed lines indicate where current capabilities are poor in capturing indirect effects.

**Figure 5—Characterizing the Baseline, Current State of the Art, and EBO Goal**

## EBO Requires New Methods of Modeling and Analysis

The study offers the following principles to make defense planning more responsive to EBO considerations:

**Mission-system analysis can increase options and make planning more realistic.** The goal of defense planning is to determine whether a mission is capable of being accomplished given all of the factors that might come into play. Current analysis tends to evaluate capability according to factors that can be measured easily, such as force size and supply times. Commanders are presented with a limited set of options under which their missions can be carried out. To include EBO options in defense planning, analysts must be able to assess mission capability in light of all of the factors that could influence a mission's outcome. They must also be able to account for uncertain obstacles and outcomes.

Figure 6 illustrates a process for mission-system analysis (MSA) that emphasizes these factors. Suppose that one wants to assess the capabilities required for a

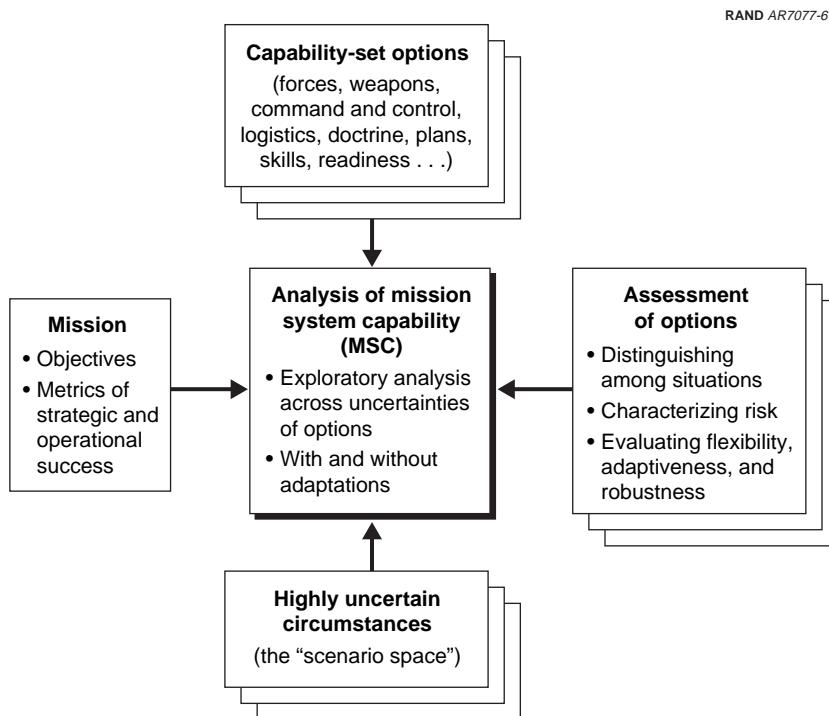


Figure 6—The Process of Analyzing Mission-System Capability

particular mission (shown at the left of the figure). First, a variety of options is proposed. Next, analysts weigh the strengths and weaknesses of each option in a “scenario space,” which envisions the potential uncertainties and problems that could arise. Finally, analysts give an assessment of the capabilities that would be required to accomplish the mission under a range of possible circumstances. The advantages of this approach are that it provides commanders and decisionmakers with a real-world, no-excuse assessment of whether a military operation will be successful and that it greatly increases the range of options available for a commander to deal with changing conditions in the field.

**To deal with uncertainty, analysts should engage in exploratory analysis, modeling, and gaming.** A key component of the MSA process is the ability to confront uncertainty head-on rather than to play down its magnitude. The uncertainty associated with EBO is often massive. This study suggests that the goal of analysis should not be to eliminate uncertainty but to deal with it in terms of probability. For example, the capability assessments described above should refer to most-likely, best-case, and worst-case outcomes. To understand the role that probability plays in various circumstances, analysts should conduct exploratory analysis using a variety of models and games. Simple models can be used for breadth, while more-detailed models and games can provide depth and can shed light on underlying phenomena. To be meaningful, this work will require major financial investment and effort in additional models, empirical knowledge, and the analysis necessary to cross-calibrate the information obtained from various sources.

**Some qualitative factors can be represented mathematically.** Current analysis often ignores qualitative factors because they are difficult to represent mathematically. However, omitting factors from a model incorrectly assumes that they have zero effect. The study finds that many factors such as troop cohesion, morale, training, and others can be represented by introducing mathematical adjustments into models. Table 1 lists the types of corrections that can be made and the magnitudes that might be used. The advantage of this approach is that it breaks down the traditional barrier between rigorous analysis and “soft factors” that are more realistic and innovative, but fuzzy. However, analysts should take care to sharpen the definitions and distinctions among situations to ensure that the corrections correspond to real-world conditions. Furthermore, although influencing enemy leaders is a major objective of EBO, cognitive processes remain difficult to model. One possible approach is to compare an opponent’s courses of action based on their most-likely, best-case, and worst-case outcomes to represent how a high-level leader might weigh the upsides and downsides of a particular decision. Analysts may be able to fine-tune this process through the exploratory analysis of models and games described above.

**Table 1—Illustrative Methods for Reflecting Soft Factors**

Factor	Example	Illustrative Magnitudes
Multipliers of capability	Multiples of force ratio for ground forces in close combat	Factors of two across different nations' armies with comparable equipment
Delay terms	Times to execute the observation, orientation, decision, and action (OODA) loop in dog fights; sensor-to-shooter delays for use of precision fires	Multiple seconds; tens of minutes
Spinup factors	Improvement in efficiency of use of air-to-ground aircraft	Improvement from 50% to 100% over seven days
Frictional coefficients	Movement rates predicted to accord more closely to historical experience than to a nation's ambitious plans	Factors of two or more
Credibility coefficients	Weapon effectivenesses much less than projected by developers, test-range results, and unconstrained simulations	Factors of three or more
Suppression factors	Multipliers of ground-force capability reducing their effectiveness for some period after heavy suppressive fires	Factors of 0.75 to 0.25

**Models and simulations should emphasize command and control.** Combat models tend to treat command and control (C2) as a support factor. The result is that C2 tends to be given short shrift and is even trivialized. Human wargames are much more realistic because they tend to be organized around strategy. Therefore, they are often more insightful and innovative than combat models and are much better at showing how commanders adapt to changing circumstances. Because C2 plays an important role in EBO, models and simulations should be developed that represent strategies and decisionmaking more explicitly.

Fortunately, some agent-based concepts and methods have been developed, primarily as the result of work at the Santa Fe Institute in the early 1990s. However, more work needs to be done to make these models applicable to operational, theater-level, and even strategic-level crises and conflicts.

### **A New Base of Empirical Information Is Needed to Inform EBO Analysis**

The principles outlined in this study will require a new base of information that sheds light on qualitative factors and supports the analysis of uncertain scenarios. It continues to be the case that only a small amount of funding is allocated to the systematic study of historical experience and experience gained in training and exercises. At the same time, EBO analysis relies more on empirical information than on concepts, notions, and wargames. Analysts should pursue a vigorous research program to gather information from history, training, exercises, and experimentation. The study offers a sample research program to illustrate how empirical data can be used to calibrate the assumptions made in models. For example, analysts might glean historical lessons about break points, the effects of strategic bombing, and other factors that are relevant to EBO. Researchers might also investigate what large-scale field tests reveal about modern march speeds and how they are affected by various types of obstacles. Further empirical data could be gathered from simulations. Research along these lines would help to make EBO analysis more accurate and relevant for real-world applications.

MR-1477-USJFCOM/AE, *Effects-Based Operations: A Grand Challenge for the Analytical Community*, Paul K. Davis

## Improving Combat Support Command and Control in the Air and Space Expeditionary Forces

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The Air Force has reorganized into Air and Space Expeditionary Forces (ASEF) whose goal is to provide effective, sustained force anywhere in the world on very short notice. This concept requires the Air Force to rethink its method of directing combat support (CS) resources to meet operational needs. Table 2 shows ASEF objectives and the CS functions required to meet them. Developing a suitable command and control (C2) framework for carrying out these functions is crucial to the Air Force's transition to the ASEF.

What are the concepts that should guide the development of a future CSC2 operational architecture? PAF researchers studied the current architecture to determine its deficiencies as well as lessons learned from the recent air war over Serbia and from preliminary analysis of Operations Enduring Freedom and Noble Eagle (Afghanistan). They also examined current Air Force initiatives and conducted interviews with functional experts across the Air Force and Joint Commands. Based on this analysis, the research team provided concepts for improving C2 methods and made recommendations to help the Air Force transition to the new concepts.

### The Current CSC2 System Has Deficiencies

Currently, the Air Force does not have a well-defined system<sup>6</sup> for carrying out CSC2 functions. The research team devised an operational architecture to describe the tasks, operational elements, and information flows that the CS community now uses to support military operations. This architecture, along with lessons learned from recent Air Force operations, revealed several deficiencies, which fall into four categories:

- *CS input is poorly integrated into operational planning.* Operations and combat support communities often carry out independent C2 activities. As a result, operational plans may be developed without adequate regard to CS feasibility. In the absence of collaboration, operational plans may prove to be

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<sup>6</sup>System is used in the general sense to mean a combination of facts, principles, methods, processes, and the like.

**Table 2—CSC2 Functionality Required to Meet ASEF Operational Goals**

ASEF Operational Need	CSC2 Requirement
Rapidly tailor force packages to achieve desired operational effects	Estimate CS requirements for suitable force package options; assess feasibility of alternative operational and support plan  Identify and preplan potential operating locations
Deploy rapidly	Determine forward operating location (FOL) beddown capabilities for force packages and facilitate rapid time-phased force deployment data (TPFDD) development
Employ rapidly	Configure distribution network rapidly to meet employment timelines and resupply needs
Shift to sustainment smoothly	Execute resupply plans and monitor performance
Allocate scarce resources where they are needed most	Determine impacts of allocating scarce resources to various combatant commanders and prioritize allocations to users
Adapt to changes quickly	Indicate when CS performance deviates from desired state and facilitate development and implementation of “get-well” plans

unsupportable or may call for unnecessary resource expenditures. Furthermore, lack of CS assessment capabilities and up-to-date and reliable CS resource information can prevent operational planners from utilizing CS input most effectively.

- *The system lacks feedback loops and the ability to reconfigure the CS infrastructure dynamically.* With limited tools for monitoring and assessing performance, it is difficult to estimate key information such as the current levels and

future arrival times of CS resources. This information must be available so that planners can respond to problems quickly and make sound decisions when operations change.

- *CS activities (particularly in the areas of transportation and distribution management) are poorly coordinated with the joint-service community.* Troubles can arise when the relative roles of the different contributors in an operation are not understood, when expectations differ on anticipated performance, or when priorities differ among the major players. Just as CS needs and capabilities must be communicated to operations planners, they must also be communicated to other services, the joint-service community, and allied/coalition organizations (if applicable).
- *The system lacks resource allocation and prioritization mechanisms across competing theaters.* Resources planned for other regions must often be diverted to support a theater preparing for or engaging in a contingency. The current system lacks the ability to quickly assess the effect that moving resources from one theater to another will have on readiness. This type of assessment must be done before resources are allocated so that high-level decisionmakers can see the effects of their allocation decisions before the fact.

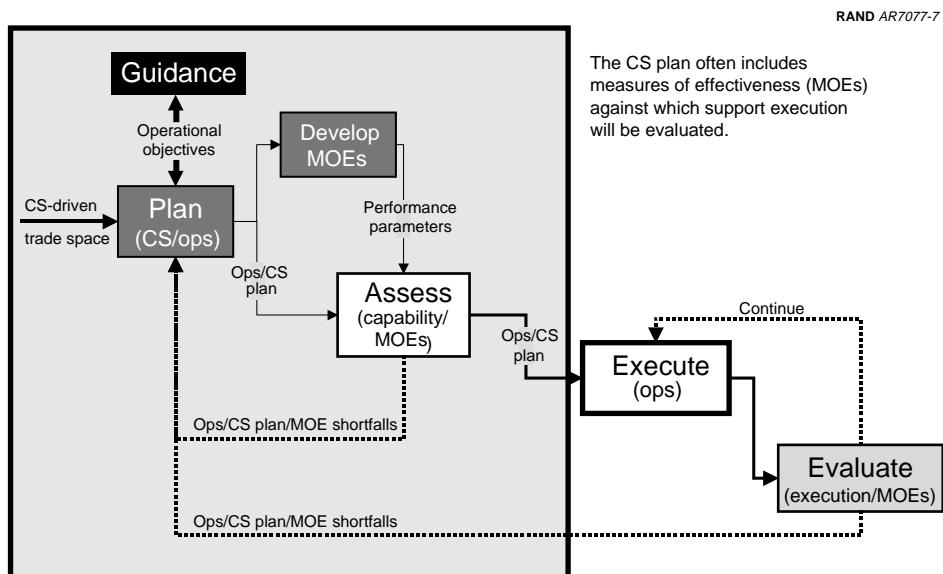
## Key Concepts Would Improve the CSC2 System

To remedy shortfalls in the current system, the research team proposed a detailed CSC2 operational architecture that would be better suited to meet the needs of the ASEF. The architecture integrates operational and CS planning in a closed-loop environment and provides feedback on performance and resources—two functions that are critical to CS effectiveness and are absent in the current system.

Figure 7 illustrates these concepts in a high-level process template that can be applied through all phases of an operation from readiness, planning, deployment, employment, and sustainment to redeployment and reconstitution. Whereas the current system calls for operators to formulate plans and assess shortfalls without CS input, the proposed system calls for cooperation between CS personnel and operators at all stages of planning, assessment, and evaluation.

A key element of the process template is the feedback loop that monitors how well the system is expected to perform (during planning) or is performing (during execution) and provides warning of potential system failures. Logistics and installation planners would know when the CS plan needed to be altered to meet changing operational requirements. Furthermore, the feedback loop might also

signal a necessary shift in the operational plan. The feedback to the operational community might be in the form of force employment options to consider that will provide the same operational effects, yet cost less in CS terms. Feedback might also involve notifying the operations community of missions that cannot be performed because of CS limitations. As a result of the feedback, operations planners would know when to revise their plans based on changes in CS capability. Together these functions would enable CSC2 to be operationally relevant, rapid, and responsive.



**Figure 7—Future Concept of Combat Support Command and Control**

### Intermediate Steps Would Facilitate the Transition to a New System

While the above concepts are intended to serve as guides for the development of a future CSC2 operational architecture, the Air Force can now take steps such as those described below to improve CSC2 functions and to prepare for the development of a new system.

- *Summarize and clarify Air Force CSC2 processes and codify them in doctrine and policy.* The Air Force should clarify the processes by which CS personnel cooperate with operators on the development of plans, assess plan feasibility,

use feedback loops to monitor CS performance against plans, and develop “get-well” planning. Clarity in these areas will make it easier to integrate combat support and operations planning in the future.

- *Create standing CS organizations to conduct command and control.* Permanent CS organizations would facilitate planning and execution as well as provide continuity when the CS community moves from peacetime to wartime functions. By collaborating with the Air Operations Center, organizations would also help integrate CS considerations into operations planning.
- *Improve training for CS and operations personnel.* Cross-training operators and CS personnel on each other’s roles can facilitate the incorporation of both aspects into operational plans. A CS curriculum should be developed and incorporated into existing and upcoming training courses. Moreover, wargames and exercises should be expanded to emphasize the importance of CS in contingency operations and to help ensure that operational and strategic personnel consider CS issues when they develop plans.
- *Enhance information systems and decision support tools.* Information systems are needed to constantly monitor CS capacity, resource inventory, and process performance levels. Tools should be developed to convert operational plans and status into CS resource requirements and then into operational capabilities. Information systems need to interface with joint-service systems. Properly integrating information from these tools will greatly reduce the chance that a plan will have to be revised in midstream and will facilitate change when necessary.

MR-1536-AF; *An Operational Architecture for Combat Support Execution Planning and Control*, James Leftwich, Robert Tripp, Amanda Geller, Patrick Mills, Tom LaTourrette, C. Robert Roll, Jr., Cauley Von Hoffman, David Johansen

## Meeting the Air Force's Maintenance Manpower Needs

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Over the past decade, the United States Air Force has had serious problems meeting its manpower needs. On one hand, a significant portion of the force has been engaged in a range of contingency and peacekeeping operations. On the other, a once-robust economy led many enlistees to leave the service in unanticipated numbers throughout the 1990s. The resulting mismatch between Air Force taskings and available personnel has underscored the need for more-accurate estimates of future manpower requirements.

To address this issue, the PAF research team conducted a detailed study of the Air Force's approach for gauging its manpower needs in the pivotal area of aircraft maintenance. The project centered on a thorough evaluation of the Logistics Composite Model (LCOM), a statistical simulation model that the Air Force uses to estimate manning requirements. Researchers also examined the Air Force-wide regulations that are used to set ceilings on the hours available for such activities.

The team developed a simple analytical construct to illustrate the Air Force methodologies. As Figure 8 shows, the black box represents the number of man-hours LCOM simulations have allocated for the accomplishment of maintainers' primary duties. By contrast, the gray box depicts the number of hours maintainers, per regulations, are unavailable for their primary tasks. Finally, the white box in the figure represents the residual time available for all the remaining Air Force tasks maintainers must accomplish in the course of their duty day. The team concludes that Air Force maintenance manpower requirements are underestimated, in large part because neither LCOM simulations nor Air Force availability rules accurately depict the actual, day-to-day challenges maintainers currently face in the field.

RAND AR7077-8



**Figure 8—A Framework for Discussing Processes for Determining Maintenance Manpower Requirements**

## The Black Box: The LCOM Process Falls Short in Several Critical Areas

The researchers found that the LCOM process suffers from several deficiencies. For example, although LCOM simulations are highly data-intensive, currently available information systems are neither consistent nor accurate enough to yield the detailed data such simulations require. To compensate for this shortcoming, field audits are typically conducted with Air Force maintenance personnel, but these audits are by nature more impressionistic than statistical. Moreover, LCOM erroneously assumes that equipment break rates do not vary over time or with the complexity of the scenario. As a result, data on such variables as break rates and fix times may well be underrepresented.

LCOM analyses were also found to omit important challenges maintainers typically face. In the fighter world, for example, many of the most stressful demands placed on maintainers arise from preparation for, workloads during, and recovery from split operations (in which a portion of aircraft pilots and maintainers is deployed overseas while the nondeploying part of the squadron remains at home). Yet such scenarios are not reflected in the model's manpower estimates. Similarly, LCOM simulations fail to account for the time maintainers devote to the crucial activity of on-the-job training. The time-intensive process of cannibalizing parts from aircraft when existing inventories fall short is underestimated in currently available data. Finally, LCOM does not explicitly address experience mix, which has a profound effect on a unit's productivity and ability to conduct on-the-job training.

## The Gray Box: Rules Governing Man-Hour Availability Are Imprecise

The Air Force's regulations that set boundaries on maintainers' primary duties were found to be lacking. In its determination of man-hour availability, for example, the Air Force applies the same rules to all members of the service, irrespective of their rank, experience level, or occupation. The same holds true for computations of indirect labor hours, which were found to be determined by—and to differ among—the major commands. This imprecision contrasts starkly with the extreme detail that characterized black-box-related activities.

Finally, as with the black box, neither Air Force man-hour availability constraints nor major commands' indirect labor assumptions explicitly address the time it takes to conduct and to receive on-the-job training.

## The White Box: Little Time Remains for Residual Activities

Manpower analysts have long assumed that after black- and gray-box-related activities have been accomplished, ample time is left over for maintainers to complete their remaining tasks. This assumption is not borne out by the team's analysis. To the contrary, the researchers found the white box—or the part of their construct that is reserved for residual activities—to be "bursting at the seams" with labor-intensive tasks that were not accounted for in the planning and programming process. These included on-the-job training, which was found to consume fully 15 to 20 percent of the duty day of experienced maintainers (the trainers); "out-of-hide" requirements, whereby up to 8 percent of senior maintainers were removed from the flight line to fill nonmaintenance duties; activities devoted to meeting high operational demands, which were reported to increase production hours by as much as 36 percent; and cannibalization of parts, which proved exceedingly time-consuming both to implement and to track. Put another way, there is evidence of an overburdened workforce whose missions could be completed only through longer working hours or through the deferral of some responsibilities.

## The Air Force Must Refine Its Methodologies

The researchers recommend that the Air Force take a number of steps to ensure that its analytical tools more accurately reflect current maintenance manpower needs.

- *Make on-the-job training an explicit requirement.* Given its direct bearing on the long-term effectiveness of the maintenance force, on-the-job training merits inclusion in LCOM analyses and in man-hour availability determinations.
- *Develop a richer scenario set for LCOM.* Steps should be taken to ensure that LCOM analyses accurately represent the environment within which maintainers must operate. In particular, such analyses should include stressful scenarios such as split operations.
- *Improve collection and analysis of equipment-break data.* To ensure that peak maintenance demands are adequately represented in LCOM, higher-quality data on equipment break rates should be collected and incorporated into the model.
- *Make man-hour availability rules more specific.* To bring gray-box and black-box activities into closer alignment, standards governing nonavailability and indirect labor hours should be better differentiated.

- *Limit overhead.* Finally, to stem the growth of the white box, the Air Force should reduce overtime either through policy changes or through increases in authorizations.

In short, the Air Force's analytical processes are no longer adequate to the task of assessing its current maintenance manpower needs. To remedy this problem, the Air Force should launch a focused effort to refine these processes so that they more closely approximate the spectrum of tasks maintainers must perform and the challenges they are most likely to face.

MR-1436-AF, *Setting Requirements for Maintenance Manpower in the U.S. Air Force*, Carl J. Dahlman, Robert Kerchner, David E. Thaler

## Alternatives for Jet Engine Intermediate Maintenance

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Traditionally, Jet Engine Intermediate Maintenance shops (JEIMs) have been located at forward operating locations (FOLs) to support military aircraft in times of war. In the past decade, however, the Air Force has sought to replace the forward presence of air power with a force that can deploy quickly from the continental United States (CONUS), commence operations immediately on arrival, and sustain these operations as needed. This concept demands a rethinking of all support concepts, including jet engine repair. The core question in accomplishing expeditionary support is the centralization of JEIM during a war as well as in peacetime.

PAF researchers studied five alternatives for locating JEIMs in peace and in war:

- *Decentralized-deployed (DecDep)*—the current system in which JEIMs are located at bases in peacetime. In times of war, part of each base's JEIM deploys with the aircraft to an FOL.
- *Decentralized-no deployment (Home)*—JEIMs are located at bases in peacetime and remain there in times of war.
- *Decentralized-forward support location (FSL)*—JEIMs are located at bases in peacetime. In wartime, one JEIM is set up in the theater to support all aircraft with a particular type of engine.
- *CONUS support location-FSL*—one JEIM in CONUS supports all aircraft in times of peace. Wartime maintenance is supported by FSLs. This alternative is identical to the previous one in times of war.
- *CONUS support location (CSL)*—all units are supported in peacetime and wartime by a single centralized JEIM in CONUS.

For each alternative, researchers simulated a two-year JEIM operation in CONUS and elsewhere that included a 100-day major regional conflict (MRC). They tested how well each configuration would support F100-229, F100-220, and TF-34 engines. The team used three criteria for evaluating the various options. First, how much equipment and personnel would be required to meet daily sortie demand in peacetime (training) and wartime? Second, at that level of resources, how many spare engines would the JEIM accumulate (or fall behind) over the course of the simulation? Finally, what transportation would be required in each alternative? Based on its findings, the study team recommended JEIM configurations for each of the three types of engines.

## The Current Method Is Too Slow in a Major Regional Conflict

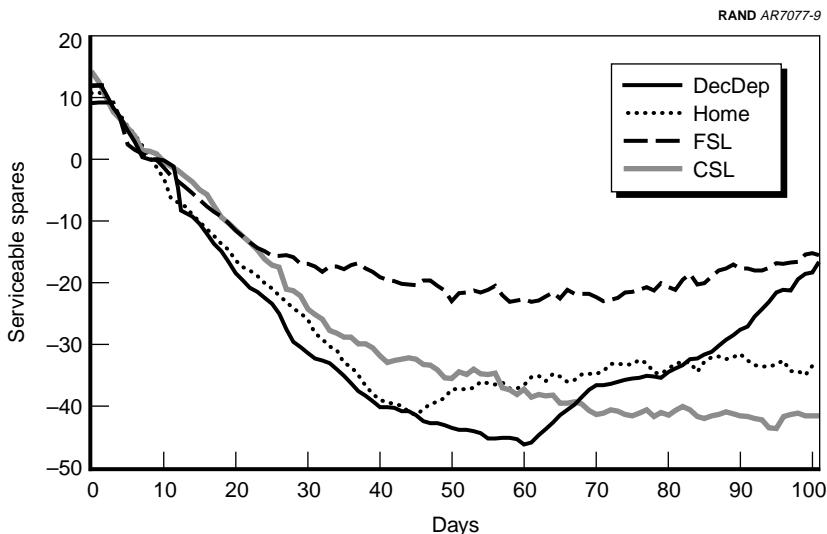
Deploying the maintenance shop along with forces proved to be the worst option for each of the three engines. The reason is that it takes too long to transport and build a fully functioning shop at an FOL. Under current plans, 30 days are required to deploy a JEIM and another 30 days to complete the test cell, which must be used on all repaired engines. In the simulation, the number of working spare engines declined sharply until 60 days into the conflict when the JEIM became fully operational. Although the shop was able to make up the deficit of spare engines by the end of the simulation, the initial drop-off makes the deployment option too risky to be reliable in a real conflict. In addition, the deployed option requires more personnel in the theater than other options. This requirement contradicts the goal of decreasing the footprint for deployment.

## FSL Is the Best Option for F100-220 and F100-229 Engines

The Air Force uses the Pratt & Whitney F100-220 and F100-229 engines for its F-15 and F-16 fighter planes. These engines have relatively high removal rates: On average, they must be removed five times for every 1,000 hours of use for scheduled and unscheduled maintenance. As a result, factors such as the number of spare engines on hand and the length of time it takes to repair and ship an engine can have a dramatic impact on how many aircraft are available to fly sorties during a conflict.

The study team determined that locating a JEIM at an FSL is by far the most effective way to support fighter planes with these engines. For example, Figure 9 compares each configuration's ability to maintain the number of available F100-229 engines over the course of the simulation. The FSL option performed much better than the other alternatives; forward support locations become operational relatively quickly. With facilities and test cells already on-site, the JEIM can begin working on engines as soon as its personnel arrive. In addition, it takes less time to transport engines between locations within the theater than to send them to a base or to CONUS. Accordingly, the data showed that the Home and CSL alternatives allowed the number of spare engines to fall sharply and to remain dangerously low.

Despite these advantages, researchers noted that the FSL option is highly sensitive to changes in transportation time. Based on actual practice, the team assumed that it would take 2–4 days to transport an engine between the aircraft and the shop (including the time it takes to prepare the engine for shipment). The simulation showed that any increase in transit time would force more aircraft to



**Figure 9—F100-229 Spares Performance for All Alternatives for the F-15 FOL**

remain on the ground while they wait for usable engines. *Thus, in an actual conflict, the benefits of an FSL configuration would depend on having reliable and efficient transportation within the theater.*

### **Either an FSL or a CSL Would Work for the TF-34 Engine**

The General Electric TF-34 is used in the A-10. Its removal rate is lower than that of the F100 engines—1.3 removals per 1,000 hours of use. As a result, the difference between maintenance options is not as dramatic as those seen above. For example, all of the alternatives showed a slow decline in the number of spare engines over the course of the conflict, but none performed poorly.

Researchers concluded that the centralized repair options would work well for the TF-34 engine. Because the TF-34 has a lower removal rate, longer transportation times (within reason) do not affect the shop's ability to keep up with demand the way they do for F100s. Thus, a single CONUS facility such as the one the Air Force now maintains at Shaw Air Force Base in South Carolina could save equipment and personnel and still do a good job of supporting the A-10 fleet in a war. At the same time, it may be prudent to include some TF-34 repair capability in FSLs to hedge against severe transportation problems. Doing so would also help to conserve the declining skill base for the TF-34 while the A-10 is phased out of the Air Force's inventory.

## The Air Force Should Pursue FSL and CSL Options

The study team made the following recommendations for the Air Force to restructure its jet engine maintenance strategy:

- *Develop FSLs to support F100s and similar engines.* The result of this analysis is broadly applicable to all current fighter engines that have similar characteristics, especially removal rates. The Air Force should proceed to develop FSLs with global strategic issues in mind. However, it must also ensure a responsive and reliable transportation system within the theater of operations for the FSLs to be effective.
- *Centralize TF-34 repair in CONUS.* The Air Force should continue to support TF-34 engines from the JEIM at Shaw Air Force Base. However, including some repair capability at FSLs would be prudent.
- *Consider centralizing peacetime repair of F100-220s and F100-229s.* The Air Force can reap additional benefits by centralizing the repair of F100 series engines in peacetime. If a centralized facility is located close to the larger bases that use these engines, substantial fractions of the transportation costs estimated in the study can be avoided.

MR-1431-AF, *Supporting Expeditionary Aerospace Forces: Alternatives for Jet Engine Intermediate Maintenance*, Mahyar A. Amouzegar,  
Lionel A. Galway, Amanda Geller

## Estimating Costs for Military Jet Engine Acquisition

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Realistic cost estimates for military aircraft play an important role in developing sound budgets and in contributing to an effective acquisition policy. Cost estimates for jet engines are based on characteristics related to performance and technology; and cost-estimation techniques must be updated as design methods, manufacturing processes and materials, and aircraft engine technology change. PAF helped develop an updated method for estimating military engine costs and also identified technological trends that are likely to affect costs in the future.

### Important Jet Engine Parameters Greatly Affect Aircraft Cost

Jet engines operate on a thermodynamic cycle that consists of three stages: compression (raising the pressure of the air entering an engine), heating (raising the temperature of the air to increase its energy greatly), and expansion (allowing the pressure of the flowing air and fuel combustion products to drop in order to extract energy and accelerate the flow). A jet engine produces thrust by changing the velocity of the air that is moving through the engine. As the engine “pushes” on the air to accelerate it, the air pushes back on the engine, providing thrust for the aircraft. The five basic components of a jet engine are the *inlet*, which controls airflow entering the engine; the *compressor*, which compresses the air; the *combustor*, in which fuel is burned with high-pressure air; the *turbine*, which extracts energy from the exhaust gases; and the *nozzle*, which accelerates the gases to produce thrust. Jet engines may be turbojet, turbofan, turboprop, or turboshaft.

Several parameters widely used to characterize the quality and performance of jet engines can greatly affect cost. Some common metrics are described below.

- *Maximum thrust* is the highest level of thrust available from a turbofan or turbojet engine.
- *Shaft horsepower* is the capability metric for turboprop and turboshaft engines, analogous to a turbofan or turbojet engine's thrust.
- *Specific fuel consumption* is the conventional fuel efficiency measure for jet engines.

- *Thrust-to-weight ratio* (for turbofans and turbojets) and *power-to-weight ratio* (for turboprops and turbofans) indicate the maximum performance available from an engine for each pound of engine weight.
- *Weight* reflects the overall size of an engine.
- *Overall pressure ratio* (OPR) is the ratio of the pressure of the air as it exits one stage of the engine to the pressure of the air as it enters a later stage. High OPR contributes to greater engine efficiency and lower fuel consumption.
- *Rotor inlet temperature* (RIT) is the temperature of the air/fuel combustion products as they enter a particular section of the turbine. A high RIT contributes to an engine's high thermal efficiency and high thrust-to-weight or power-to-weight ratio. Because of the difficulty of designing for higher RITs, the RIT is a good indicator of the level of technology in a modern jet engine.
- *Engine component life* is the amount of time the engine can be expected to perform safely.

## Cost-Estimation Methods Have Been Updated

Methods for estimating aircraft engine costs have traditionally been based on historical cost data for various engines. Cost estimators typically analyze data on development and production costs and aircraft quantities produced for each type of engine. They use engine characteristics such as those described above to conduct statistical regression analysis and produce equations known as cost-estimating relationships (CERs). PAF researchers updated the approach used in previous studies by using more-recent cost data that capture the effects of newer technology, separating the cost data for different types of engines, and treating each engine model separately.

Through statistical analysis, the researchers explored the possible performance, programmatic, and technological parameters that affect engine development costs, production costs, and development schedules. Their results indicate that rotor inlet temperature—an engine characteristic that affects performance and also reflects the level of technology—is a significant factor in most CERs. Based on the updated CERs, they also found that an advanced-technology new engine would have significantly higher development costs and would take longer to develop than a derivative engine (one based on an existing model) using evolutionary technologies.

Given the high degree of uncertainty regarding the direction of future military aircraft development, cost analysts should continue working with the engine

manufacturing industry to monitor changes in practice and technology that will be incorporated into future aircraft. They should also continue collecting data on the actual cost of aircraft jet engine development and production. Both practices will improve the quality of future cost-estimating tools.

### Trends in Jet Engine Technology Will Affect Future Costs

In the last two decades, the jet engine industry has designed and produced new military and commercial engines with greatly improved performance, efficiency, and life expectancy. Other improvements, such as reduced emissions and less noise, are currently in development. Several new technologies are now being integrated into major engine development programs for the first time. The following list of technologies highlights many key design elements that cost analysts are likely to encounter over the next two decades when examining options for military aircraft engines.

- *Low observables.* Without proper precautions, an aircraft engine can produce observable “signatures,” such as strong radar returns, infrared emissions, noise, and visual signatures. Creating low-observable aircraft involves special materials, shaping, and handling.
- *Integrally bladed rotors.* Also known as bladed disks or “blisks,” these one-piece units make up the rotating portion of a fan or compressor in a jet engine. Integrally bladed rotors provide advantages because they reduce weight and part count, and they improve aerodynamic performance. On the other hand, they are more difficult to repair than other types of rotors, and they require more careful design to avoid undesired vibrations.
- *Alternative engine lubrication systems.* Due to the vulnerability of oil-based lubrication systems, the engine production community is considering two oil-free lubrication systems: air bearings and magnetic bearings. Both types still require further development, but in future engines, they may be integrated in a hybrid fashion with conventional oil-lubricated bearings to provide augmentation at high gravitational forces.
- *Mechanical thrust-vectoring nozzles.* Thrust vectoring (turning the engine’s exhaust to change the direction of the thrust force) enables exceptional aircraft maneuvering and reduces the need for large aerodynamic control components, such as a horizontal tail, on the aircraft. However, thrust-vectoring nozzles require thousands of moving parts, which make the nozzles expensive and difficult to design.

- *Fluidic nozzles for thrust-vectoring engines.* Fixed-geometry fluidic nozzles are an attractive alternative to mechanical thrust-vectoring nozzles because they do not have any moving parts in contact with the engine's hot exhaust jet. They should eventually be much cheaper to design, produce, and maintain than mechanical thrust-vectoring nozzles, but the technology is still in its early stages and will likely take several years to mature.
- *Integral starter-generators.* Integral starter-generators are alternators that will be manufactured as integral parts of engine spools. Their use will reduce both cost and weight and will increase reliability by eliminating the engine's power-takeoff assembly. However, like other new technologies, these components are still several years from maturity.
- *Prognostics and engine health management.* Advanced engine health monitoring systems, including prognostics and diagnostics, along with electronic technical manuals, should reduce the total labor required to maintain engines and allow maintenance crews to plan for and perform preventive maintenance more effectively. While these capabilities should eventually result in operations and support (O&S) savings, they will add to development costs until this technology is more developed.
- *Advanced fuels.* Advancements in jet engine fuels are primarily geared toward creating fuels that can withstand higher temperatures without breaking down. This results in better safety, operability, and maintainability of engines (rather than increased power). Use of these fuels may significantly affect O&S costs as the cost of fuel and engine maintenance change.
- *Pre-cooled cooling air.* Using cooling air that has itself been pre-cooled reduces the amount of air needed to cool jet engines that have high combustion temperatures. However, the required heat exchanger will add to the engine's complexity, part count, weight, and observability and thus will affect development, production, and O&S costs.
- *Advanced materials.* While early engines were made mostly of steel, today's engines are made from a variety of materials, including nickel-based super-alloys, titanium, aluminum, steel, and composites. Considerable research is being conducted on the use of ceramics and intermetallic alloys for their strength, temperature endurance, and weight advantages over current materials.

MR-1596-AF, *Military Jet Engine Acquisition: Technology Basics and Cost-Estimating Methodology*, Obaid Younossi, Mark V. Arena, Richard M. Moore, Mark Lorell, Joanna Mason, John C. Graser

## **Globalization of the Defense Aerospace Industry: What Does It Mean to the U.S. Air Force?**

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Between 1990 and 1998, there were drastic changes in the U.S. aerospace industry. The number of credible U.S. prime contractors building fighters and bombers fell from seven to two; the number of U.S. missile manufacturers from fourteen to four, and the number of space launch vehicle producers from six to two. By the end of the 1990s, the European defense aerospace industry had also begun to experience a dramatic consolidation and restructuring. The growing consolidation of defense prime contractors has been accompanied by increased numbers of strategic and product-specific alliances, international teaming and joint ventures, and cross-border mergers and acquisitions among defense firms, along with heightened interest in foreign exports and foreign lower-tier suppliers.

Because the globalization of the aerospace defense industry is relatively recent, its effects are not well understood. PAF undertook an assessment of the extent of this phenomenon and the implications for U.S. defense planning. During the initial phase of the study, the research team found that leading U.S. aerospace contractors are aggressively seeking new forms of cross-border relationships and that global linkages among defense firms are becoming more numerous and more complex. The United States can no longer seek simple, bilateral collaborations between itself and specific foreign countries. The growing trend toward increasingly complex industry linkages presents the U.S. government and the aerospace defense industry with new opportunities as well as risks.

The most visible evidence of the globalization of the U.S. defense aerospace industry is the growing number and value of cross-border transactions. A key finding of the study, however, is that the U.S. aerospace industry is far less globalized than other high-technology and manufacturing sectors of the economy. To date, the U.S. aerospace industry has participated in the global economy primarily through exports. The United States is the world's leading arms exporter, accounting for about half of all shipments. However, the United States imports far fewer aerospace products. In addition, U.S. military aerospace producers are much less internationally active than their nonmilitary counterparts. However, many leading executives in the U.S. aerospace industry support greater globalization both for the potential economic benefits and for market access.

## **Implications of European Consolidation and Increased Aerospace Globalization**

U.S. industry collaboration with one country's firm increasingly means collaboration with many countries' firms. This raises serious new questions about technology and export control policies. The European defense aerospace industry is in the process of consolidating down to one or two dominant European transnational companies in nearly every major product sector. The three leading European companies—BAE Systems, EADS, and Thales—are intertwined with one another and with many other European defense contractors through a complex web of joint ventures, collaborative programs, cross-ownership, mergers, and acquisitions. Other important foreign industrial bases, such as those of Israel and Korea, are also consolidating and are increasingly forming strategic links with the new European mega-firms and with many other foreign companies located in different parts of the globe. As a result of this increased interrelatedness, the traditional practice of negotiating bilateral, country-specific agreements no longer applies. In light of the complexity of these relationships, the United States will have to be vigilant to ensure that future partnerships continue to promote U.S. economic, political, and military objectives.

Consolidated European and other foreign firms mean potentially more equal partners as well as stronger competitors. The consolidation of the European defense aerospace industry is producing pan-European companies of roughly the same size and sales turnover as the leading U.S. defense contractors in many product sectors. Increasingly, these new pan-European companies are becoming financially and technologically competitive with the leading U.S. firms. They are also eager to offer weapons solutions that compete with U.S. products in the European and other foreign markets. U.S. aerospace companies are concerned about these changes in the competitive landscape, particularly with respect to future market opportunities abroad.

Global strategic business relationships can promote as well as complicate standardization and interoperability. The situation is complicated by the fact that the defense industries of other important non-NATO allies have been aggressively seeking both U.S. and European market access through the formation of new business relationships based on strategic alliances. In many cases, these alliances have clearly increased competition in key niche product sectors within both the U.S. and European markets in a manner that appears to be beneficial to the Air Force. However, in some instances, the relationships seem to have undermined U.S. attempts to promote equipment standardization and interoperability.

## **Globalization of the Aerospace Defense Industry— Opportunity and Risk**

If new cross-border collaborative business relationships continue to flourish, the consolidation of European and other foreign industries potentially increases the prospects for allied procurement of standardized or interoperable systems. This would enhance the cohesion of U.S. alliances and the ability to conduct coalition-led operations while potentially reducing system costs. On the other hand, there is also the risk of fragmentation. Disagreements over standards, along with the increased capabilities and competitiveness of European and other multinational defense industries could lead to the creation of more indigenous solutions and widespread global competition with U.S. firms. This in turn could reduce alliance cohesion, equipment standardization, and system interoperability, and it might encourage the spread of nonstandard solutions to European weapons requirements.

### **Directions for Future Research**

The results of this research highlight the need for greater understanding of the consequences of an increasingly global aerospace industrial base. Accordingly, a proposed follow-up study will address three key questions:

- Given the need for the United States to safeguard its defense technology in the interest of national security, how much competition and equipment standardization is possible among firms?
- How well do recent regulations geared toward enhancing global partnerships promote U.S. national security objectives such as maintaining technology security and critical national capabilities?
- How will European domestic industrial, political, and military factors affect the prospects for greater transatlantic collaboration and further globalization of the U.S. defense industry?

Further analysis of these issues will help the Air Force develop new strategies and policies to promote U.S. defense objectives within the increasingly global defense industry.

MR-1537-AF, *Going Global? U.S. Government Policy and the Defense Aerospace Industry*, Mark A. Lorell, Julia Lowell, Richard M. Moore, Victoria Greenfield, Katia Vlachos

## Innovative Acquisition Management: The High-Altitude Endurance Unmanned Aerial Vehicle Program

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Unmanned aerial vehicle (UAV) development programs frequently have failed, either because of inadequate integration of program elements (e.g., sensor, platform, and ground elements) or costs far exceeding what acquiring agencies are willing to pay. To overcome these failures, an innovative acquisition strategy was introduced for the development of the High-Altitude Endurance (HAE) UAV. Under the sponsorship of the Defense Advanced Research Projects Agency (DARPA) and the Air Force, RAND analyzed this strategy for its effects and its applicability to other acquisition efforts.

The HAE UAV program sought to develop two different UAVs and their ground and support segments. The first, Global Hawk, was a conventional UAV. The second, DarkStar, included low-observability features. The program had three phases. Phase I was a competitive design phase for the conventional configuration; Phase II was the development and testing of both UAVs; and Phase III focused on demonstration and evaluation.

### **The Program Combined Acquisition Initiatives in Innovative Ways**

The HAE UAV program included several features that had never before been used in combination. The program strategy was designed to facilitate the demonstration and deployment of a new capability that might not otherwise have been advocated. Its specific elements are summarized below.

- Section 845 Other Transaction Authority (OTA) provided a blanket waiver for all Department of Defense (DoD) acquisition regulations and program management procedures, Federal Acquisition Regulations processes, and key legislation such as the Competition in Contracting Act.
- Advanced Concept Technology Demonstration (ACTD) designation placed firm boundaries on total program cost and schedule, streamlined reporting and oversight, and set as an objective the demonstration of operational concepts and military utility.
- The sole formal program requirement was a Unit Flyaway Price (UFP) of \$10

million (FY 94 \$) for the 11th through 20th air vehicles produced. This included all flight hardware and contractor profit.

- Performance parameters were stated as goals rather than requirements. This approach allowed a high degree of design flexibility.
- Use of Integrated Product Teams (IPTs) facilitated collaboration between multiple contractors for each system and between the government and contractors managing each system development effort.
- A small government program office encouraged industry to manage the program efficiently.
- A high degree of contractor design authority and management responsibility encouraged efficiency as well as technological and management innovation.
- Early user involvement sought to determine military utility well before a commitment to production was made.

### **Program Performance Was Sometimes Mixed**

The innovative acquisition strategy had significant effects, both positive and negative, on program execution and outcomes.

- *Flexibility.* Use of Section 845 Other Transaction Authority added a high degree of flexibility and tailoring to the relationship between the government and contractors. The effects of this flexibility depended in large part on the skills, experience, and personalities of the program managers and contracting officers. Reliance on individuals is a key difference between OTA and a more traditional contracting strategy. This flexibility was not always appropriate; for example, it led to early systems engineering processes for both DarkStar and Global Hawk that were inadequate given the complexity of the projects.<sup>7</sup> Adequate processes were not established until the middle of Phase II for both programs. Among its positive effects, OTA eliminated costs associated with DoD and Federal Acquisition Regulation processes and reporting requirements. It allowed for quick, nonbureaucratic responses to external changes such as those in funding levels as well as to lessons learned in the course of the program. OTA also enhanced the collaboration between government and contractor personnel fostered by the Integrated Project Teams.
- *Complications of ACTD designation.* The ACTD designation resulted in significant challenges for follow-on acquisition and budgeting, particularly as the

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<sup>7</sup>See Jeffrey A. Drezner, Geoffrey Sommer, and Robert S. Leonard, *Innovative Management in the DARPA High-Altitude Endurance Unmanned Aerial Vehicle Program: Phase II Experience*, RAND, MR-1054-DARPA.

program moved into the formal acquisition process. This can be expected in all ACTD programs that begin without an approved operational requirement. Differing expectations regarding the entry point in the formal acquisition process led to tensions among program participants. At the same time, the ability to begin a program without an approved Operational Requirements Document is a key strength of ACTD programs. It provides a mechanism for demonstrating innovation or introducing a new capability into the operational forces, opportunities that almost certainly would not have been available given the absence of a constituency for high-altitude endurance UAVs.

- *UFP requirement.* The requirement for a \$10 million UFP for units 11 through 20 was unattainable. This target had not been substantiated through careful analysis. Rather, it was chosen to be high enough to provide any resulting system with some meaningful capability but low enough to ensure that the Air Force would accept it. In setting this requirement, planners had to contend with implicit (though misguided) assumptions that unmanned vehicles were less complex, and therefore should cost less, than manned vehicles. When the contractor suggested eliminating some functionality in order to meet the UFP requirement, DARPA was unwilling to do so. The UFP requirement succeeded, however, in instilling a degree of cost consciousness and a resistance to requirements “creep” not normally seen in major defense acquisitions.
- *Performance parameters.* Stating performance parameters as goals allowed flexibility that helped control costs. This flexibility allowed contractors to emphasize certain system aspects at the expense of developing others. Some capabilities deemed desirable later in the effort, such as faster mission planning abilities and easier system support, were not emphasized during development of the ACTD and were found lacking during demonstration and evaluation efforts. The flexibility of performance requirements also added ambiguity to the military utility assessment and later contributed to difficulties in defining operational requirements as the Global Hawk program entered the formal acquisition process.
- *Integrated Product Teams.* The IPT structure supported and enabled positive aspects of several elements, including OTA and increased contractor authority. IPTs with both government and contractor personnel were used extensively in the Global Hawk program. Although clashing personalities and organizational cultures created some problems within Global Hawk IPTs, their effectiveness improved considerably over time. DarkStar contractors were less inclined to allow government personnel to join their IPTs. Similarly, these contractors did not participate in the IPTs of other contractors. This almost certainly exacerbated the program’s difficulties.

- *Program office size.* Both government and industry program offices remained relatively small throughout the program. The Air Force program office grew to accommodate planning for the transition to the formal acquisition process but remained small relative to other highly visible Air Force programs.
- *OTA implementation.* OTA gave the contractors increased authority and responsibility for design, trade-off analyses and decisions, development activities, and the test program. This had some benefits in accelerating decisions and enhancing business process flexibility, but it also contributed to problems in DarkStar aerodynamics as well as to increased costs and lengthened schedules for Global Hawk resulting from early inattention to system integration.
- *User involvement.* The Joint Forces Command was designated as the user for the HAE UAV ACTD program. Early user involvement yielded clear benefits by providing focus and emphasis to the program and in guiding the subsequent development effort. Unified commands such as Joint Forces Command, however, do not have the resources or expertise to be fully interactive in the development process. In contrast, the Air Force Air Combat Command, the operational user for the HAE UAV, has the necessary resources and expertise, but it was not involved until post-ACTD planning began. These circumstances resulted in considerable tension between the designated ACTD user and the operational user.

## Overall, This Strategy Produced Positive Results

This study's overall assessment is that, despite some difficulties, many innovations introduced in the Global Hawk and DarkStar ACTD programs have great potential for improving acquisitions of other systems. The innovative management of the ACTD led to many program successes. It was highly flexible and responsive to changes in circumstances. It was easily modified to incorporate those changes. It helped focus efforts on demonstrating a new capability that allowed prioritization of competing objectives and interests. Above all, the study team noted that the ACTD was ultimately successful in demonstrating a valuable capability that likely would not have otherwise been developed, and one that has already been put to use.

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<sup>8</sup>While DarkStar did not advance beyond the ACTD program, Global Hawk entered the formal acquisition process. Some Global Hawk systems were used in their ACTD configurations in recent operations over Afghanistan.

MR-1473-AF, *Innovative Development: Global Hawk and DarkStar—Their Advanced Concept Technology Demonstration Program Experience, Executive Summary*, Jeffrey A. Drezner, Robert S. Leonard

## Is the United States Ready for Toxic Warfare?

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“Toxic warfare” is the use of chemicals and industrial waste to harm or alter the behavior of an opponent during military operations. There have been many incidents of toxic warfare in recent years. In 1986, for example, the Liberation Tigers of Tamil Eelam poisoned tea with potassium cyanide in an effort to cripple the Sri Lankan tea export industry. In 1990, during the Gulf War, Iraqi forces retreating from Kuwait caused the release of crude petroleum from field production facilities and ignited the oil in efforts to slow advancing coalition forces—the only time U.S. operations have faced a toxic attack. In the mid-1990s, Serbian forces launched six attacks on the Croatian Petrochema facility that stored large quantities of anhydrous ammonia and a variety of other potentially hazardous chemicals. Had the attacks been successful, lethal concentrations of chemicals would have spread over a wide area. Toxic weapons have also been used in conflicts in the Middle East, Russia, Chechnya, and Colombia.

To date, instances of toxic warfare have not been analyzed extensively, largely because researchers and military planners have focused on nuclear, biological, and chemical weapons. However, an evaluation conducted by Project AIR FORCE indicated that toxic weapons merit greater attention as part of U.S. military and civilian crisis-response planning. PAF reviewed incidents involving toxic weapons and evaluated the risk they pose to U.S. expeditionary forces and the U.S. homeland. The major finding was that these weapons provide an attractive option for both state and nonstate actors (including insurgents and terrorists) because they are inexpensive, plentiful, and not entirely secure from theft or diversion. Moreover, they provide a means for hostile state or nonstate actors to improve their capabilities within the context of “asymmetrical” warfare—attacking an adversary’s points of vulnerability and seizing opportunities to use unexpected means of attack.

### How Are Toxic Weapons Used in Warfare?

Toxic weapons are most commonly composed of hazardous materials such as irritants, choking agents, flammable industrial gases, water supply contaminants, oxidizers, chemical asphyxiates, incendiary gases and liquids, industrial compounds, and organophosphate pesticides. Various forms of toxic waste such as spilled petroleum, smoke, refuse, sewage, and medical waste may also be used in toxic weapons. Toxic warfare may take the form of the poisoning of a water

supply with chemicals, sewage, or pesticides. It may mean the release of chemicals, gases, and smoke, either as weapons themselves or as part of traditional weaponry such as bombs and rockets. Toxic waste poses yet another threat, especially because an increasing number of U.S. operations are being conducted in urban industrial areas with decaying chemical infrastructures.

Toxic warfare has three main objectives:

- *Create health hazards.* Toxic warfare can cause casualties among opposing militaries by incapacitating and, in some cases, killing the adversary.
- *Damage or contaminate the military or civilian infrastructure.* Toxic warfare can halt or force delays in military logistics flows or operations and can disrupt the functioning of the urban infrastructure through contamination or corrosion. Water supplies are especially vulnerable to intentional and accidental contamination. Toxic smoke can be used to cause confusion, impair vision, and otherwise disrupt military operations.
- *Induce psychological effects resulting from the actual or threatened use of toxic substances.* Toxic substances often represent an unknown threat, and the uncertainty surrounding the potential damage these substances might cause can increase their impact even when little or no physical harm has been done.

In contrast to chemical weapons, which involve the use of banned substances such as the nerve agents sarin and soman, the chemicals and industrial wastes that are used in toxic weapons are usually legal, abundant, inexpensive, and readily available. In fact, one reason that toxic weapons pose such a threat is that the materials required to make them are so ubiquitous. Large industrial facilities are obvious sources; but toxic materials are also available at airports, college laboratories, and even garden-supply warehouses. Table 3 lists some toxic materials and where they can be found in urban areas. Toxic materials are also available from the illegal chemical and toxic waste sites—both industrial and medical—that can be found throughout North America, Europe, the Middle East, and probably East Asia.

### Toxic Weapons Seem to Be a Growing Threat

New trends in toxic warfare have emerged. In recent years, sophisticated terrorist organizations have demonstrated their interest in toxic weapons and have taken more opportunities to use them. Moreover, these groups have used toxic weapons in conjunction with more complex forms of organization, training, and

**Table 3—Locations of Toxic Materials in Urban Areas**

Location	Toxic Materials
Airports	Aviation gasoline, jet fuel
Barge terminals	Bulk petroleum and chemicals
College laboratories	Organic chemicals, radioactive material
Electronic manufacturers	Arsine, arsenic trichloride
Farm and garden-supply warehouses	Pesticides
Food processing and storage areas	Ammonia
Glass and mirror plants	Fluorine, hydrofluoric acid
Hard rock ore mines	Potassium and sodium cyanide
Inorganic chemical plants	Chlorine
Landscaping businesses	Ricin
Medical facilities	Radioactive isotopes, mercury, waste
Pesticide plants	Organophosphate pesticides
Petroleum storage tanks	Gasoline, diesel fuel
Photographic supply distributors	Cyanides, heavy metals
Pipelines and propane storage tanks	Ammonia, methane, propane
Plastic manufacturers	Isocyanates, cyanide compounds
Power stations and transformers	Polychlorinated biphenyls (PCBs)
Rail and trucking lines, chemical manufacturing plants	Anhydrous ammonia; sulfuric, phosphoric, and hydrochloric acids; flammable liquids; chlorine; peroxides; other industrial gases

equipment. For example, Al Qaeda has shown an interest in toxic warfare ever since the 1993 World Trade Center car bombings, when it used cyanide in a bungled attempt to cause a toxic attack along with the bombings. Raids on Al Qaeda cells in Europe and Afghanistan have uncovered manuals clearly illustrating that Al Qaeda terrorists were considering the deployment of toxic weapons, especially ricin.

Toxic weapons have also been used more often in exotic combinations. For example, in March 2001, FARC (the Revolutionary Armed Forces of Colombia)

attacked the police station in Puerto Lieras, Colombia, with pipe bombs loaded with a combination of glue, sulfuric acid, gasoline, tar, and feces.

## The Threat to U.S. Forces Abroad

The U.S. military is currently seeking to improve its ability to respond to toxic warfare by organizing, training, and equipping for such warfare and by updating military field manuals and related documents accordingly. At the same time, however, the level of threat that toxic weapons represent remains to be determined.

Should toxic warfare be considered a mere nuisance or a threat of strategic concern? Although it is impossible to know how extensively toxic weapons will be used in the future, there are several reasons to conclude that toxic warfare merits serious consideration as part of planning strategies.

- Overall, the U.S. military is actively aware of the potential for toxic warfare but not where toxic threats exist.
- At the operational level, U.S. forces currently have no tailored response to toxic warfare in doctrine. Forces could be required to carry chemical kits, protective clothing, and cleanup materials on every operation. However, doing so would impede their mobility and agility.
- The use of toxic weapons has implications for U.S. military lift and logistics. As base security becomes more critical to operations, the vulnerability of key logistics sites has emerged as an important issue. Many sites—including ports, airfields, and related fixed sites that serve as choke points—are vulnerable to toxic attack. Support staging areas as well as rail and road networks are also potential targets, as are intermediate and infrastructure logistics bases.
- At the tactical level, U.S. armed forces may not be ready for toxic warfare. The Office of the Secretary of Defense has found a number of problems associated with preparation for toxic warfare as a subset of a nuclear, biological, or chemical attack.
- Cleanup from a toxic attack may prove difficult and put equipment out of service until after a conflict is over. The decontamination of aircraft is especially difficult, as demonstrated when oil-laden rain fouled the equipment of coalition forces during the Gulf War. Cargo may require extensive decontamination measures, specialized and highly sensitive monitoring equipment, and extended weathering or destruction.

## The Threat Within the United States

Toxic weapons are a threat not only for U.S. forces engaged in military operations in other countries but also for military installations and civilians within the United States. The combination of large population centers and the wide availability of toxic materials throughout the United States poses a threat from terrorists who might use toxic weapons as part of a deliberate attack. In addition, accidents, incompetence, or employee malevolence could produce toxic incidents with significant implications for civilian populations.

## How Can the United States Defend Against Toxic Warfare?

The U.S. understanding of and response to the threat of toxic warfare have been slow to mature, but they have improved recently with the development of counter-terrorism operations within the United States and with the U.S. military's efforts aimed at preventing and responding to toxic warfare abroad. However, more can be done.

### *Protect U.S. Forces Abroad*

Although the identification of specific threats is a painstaking process, the U.S. military needs to improve its knowledge of the locations of both legal and illegal sources of toxic waste. It should resolve at the doctrinal level the trade-off between force protection and mobility/agility and develop procedures for addressing threats to military lift and logistics. The military also needs additional policy and guidance at the tactical level, integrated training and exercise programs, first-responder equipment, and decontamination procedures at fixed sites as well as for cargo and equipment.

### *Defend the Homeland*

U.S. officials have been concerned about toxic warfare attacks on U.S. territory for some time, and overall awareness has improved. Since 1996, the year the Olympic Games were held in Atlanta, the United States has routinely taken active measures to prepare for special events. Gilmore Commission<sup>9</sup> members are dis-

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<sup>9</sup>The Gilmore Commission is a federal advisory panel headed by Virginia Governor James Gilmore. Established at the direction of Congress in October 1998, the panel is charged with assessing domestic response capabilities for terrorism involving weapons of mass destruction. The Department of Defense, in consultation with the U.S. attorney general, the secretary of Energy, the secretary of Health and Human Services, and the director of the Federal Emergency Management Agency, contracts with RAND to support the group—by selecting panel members, for example—through one of its federally funded research and development centers.

cussing prevention, preparedness, mitigation, and response scenarios for hazardous material incidents in the continental United States as well as for chemical, biological, radioactive, and nuclear agroterror and cyber threats.

One issue of great concern is the potential vulnerability of chemical and industrial facilities. In the aftermath of September 11, 2001, some U.S. industries have increased the precautions they take to protect their facilities. The chemical industry, for example, issued stringent new site security guidelines, and industry officials say they are in daily contact with the FBI and other federal authorities to prepare for a direct threat against a chemical plant. Protective measures have also been temporarily increased to provide safeguards for industrial facilities and operations as well as to forestall the potential for retaliation during U.S. military operations. Despite these measures, the threat from toxic releases is substantial. According to "worst case" scenarios that chemical companies are required by law to file with the Environmental Protection Agency, a single accident at any of the nearly 50 chemical plants operating between Baton Rouge and New Orleans could potentially put at risk 10,000 to 1,000,000 people. Environmental and hazardous chemical experts say that serious security problems may also persist to varying degrees at chemical manufacturing centers in Texas, New Jersey, Delaware, Philadelphia, and Baltimore.

At the forefront of toxic warfare in the United States are the first responders—personnel from medical and law enforcement or security organizations, fire-fighters and rescuers, hazardous materials investigators, and explosive ordnance disposal experts. U.S. domestic first responders are organizing, training, and equipping to counter potential attacks.

Other aspects of the U.S. crisis response network are deficient. There is no consistent approach to burden sharing among agencies, particularly with regard to treating casualties. Internet connectivity in many hospitals remains poor, with only 25 percent of laboratories up to federal standards for access and dissemination of information. Better opportunities for agencies to share information and coordinate efforts need to be identified.

Effective coordination must also be established between military and civilian crisis-response preparedness efforts. The U.S. military possesses chemical weapon prevention and cleanup expertise that is applicable to homeland security. Civilian crisis-response personnel can, for their part, provide expertise in areas such as hazardous materials.

Finally, the risks associated with toxic warfare—both for U.S. forces abroad and for military installations and civilians within the United States—must be better understood. Planning for military operations and civilian crisis response should

be based on detailed knowledge of the benefits and costs associated with various options for countering toxic weapons. A quantitative risk assessment would provide a more thorough evaluation of the problem.

MR-1572-AF; <i>Toxic Warfare</i> , Theodore Karasik
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## Russia's Decline: A New Threat to the United States

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Since the end of the Cold War, Russia has been in a relative state of decline. Political decentralization, a fractured economic system, ethnic and regional tension, and a weakened military continue to constrain the country's progress toward the post-Soviet goals of a stable federal government and a thriving market economy. While highly unlikely, continued decline could at worst bring about the collapse of the Federation. Even short of state failure, however, the very processes of decline could cause instability and unrest, which would have serious consequences for Russia and its neighbors. Moreover, the United States maintains interests in the region, which include ensuring the safety of European and Asian allies, securing and transporting energy resources from the Caspian Sea, preventing a nuclear disaster, keeping weapons of mass destruction and related material out of the hands of terrorists, and alleviating mass human suffering. A conflict within a destabilized Russia, an armed conflict between Russia and another country—authorized or unauthorized—or a humanitarian disaster could well demand U.S. military involvement, with a large portion of responsibility being borne by the Air Force.

How can the United States best prepare for the possibilities and dangers inherent in Russia's continued decline? PAF researchers analyzed recent trends in Russia's economy, political development, military structures and thinking, and other critical areas to determine where possible dangers might lie. They also envisioned crisis scenarios and the demands that they would place upon the U.S. military. The research team concluded that, while it is premature to say that Russia is heading toward failure, the potential dangers of its continued decline call for a new focus in U.S. policy and planning with respect to Russia. The United States can help limit the extent of Russia's decline by improving bilateral relations and increasing cooperation on a range of mutually important issues. Furthermore, the U.S. military and the Air Force in particular can take steps to ensure their readiness to deal with potential crises.

### Russia Suffers Declines in Multiple Key Areas

The study identifies several trends in Russia's decline that could contribute to the destabilization of the country and weaken its ability to respond to potential crises.

- *Political decentralization.* The regions that Russia comprises have become increasingly autonomous and economically isolated, with local governments gaining significant power. In response, tensions have developed between the regions and the central government in Moscow. Interregional friction also exists because of the uneven distribution of resources and power.
- *Compromised democratic freedoms.* The stability of Russia's democratic institutions is questionable. Local political parties are weak, with entrenched political elites wielding most of the power. Local elections are often manipulated to favor specific candidates and to prevent others from running. Meanwhile, Moscow's efforts to reassert political control more broadly have included the suppression of free speech in the electronic and print media.
- *Economic disarray.* The infusion of foreign aid into the Russian economy and success in only a few key sectors have enabled small groups and individuals to amass huge amounts of wealth that is unevenly distributed throughout the country. There is also a growing trend toward demonetization, in which trade or barter is used as a means to pay off debt. In addition, capital flight has caused over \$100 billion to be sent abroad in the last decade. Finally, there has been a rise in rampant crime, corruption, and a shadow economy. Although there have been signs of economic improvement in recent years, it is uncertain whether these positive trends are sustainable.
- *Demographic decline.* Russia's population is declining through migration, lower birth rates, and higher mortality rates, particularly among working-age men. Premature deaths have been linked to alcoholism, violence, and infectious and noninfectious diseases. With viral hepatitis, tuberculosis, and HIV infections on the rise, the health care system is on the brink of a crisis.
- *Military weakness.* Military personnel are distrustful of Putin after his failure to fulfill campaign promises to improve the military. Moreover, increased burdens on local authorities to pay, feed, house, and supply soldiers have fostered regionalization that could call into question the soldiers' loyalty to Moscow. Soldiers themselves are often in poor health, undereducated, untrustworthy, and poorly trained, and the equipment they use is generally outdated or inadequately maintained.
- *Vulnerability of nuclear facilities.* Russia's nuclear facilities—both military and civilian—have deteriorated. Aging early warning systems are geared toward retaliation rather than prevention of an accidental launch and are therefore more likely to malfunction. It is uncertain whether Russia's nuclear weapons have unlocking codes and, if so, who has access to them. In addition, most of Russia's aging nuclear power reactors have been deemed irredeemably unsafe, but they continue to operate. Employees in the industry are underpaid and work in poor conditions, increasing the possibility for sabotage or corruption.

- *Loss of transportation infrastructure.* Russia's transportation infrastructure has decayed significantly since the Soviet years. No paved road runs all the way across Russia. Those roads that do exist are overused and are located primarily in the more populous regions of the country. In addition, Russian railways are ill maintained, though some efforts have been made to improve them in recent years.

### Crisis Scenarios Could Place Demands on the U.S. Military

While some might argue that Russia's weakness, or even the potential for its eventual collapse, has little to do with the United States, the truth is that a number of U.S. interests are directly affected by Russia's deterioration and the threats that it embodies. The study identified a range of scenarios that could result from Russia's continued decline in the areas noted above. These include authorized or unauthorized belligerent actions on the part of disgruntled military troops; border clashes with neighboring states; the emergence of nuclear-armed terrorist groups; the eruption of civil war with fighting near nuclear, chemical, or biological weapons sites; a nuclear or chemical accident; ethnic conflict leading to refugee problems; fighting in the Caucasus that threatens oil and gas pipelines; a massive ecological disaster spreading famine and disease; an increasingly criminal economy that threatens the economies of other countries; and the proliferation of weapons of mass destruction.

A U.S. military response to any of these crises would include tasks for the Air Force: transport; security; peace enforcement; logistical support; reconnaissance; and command, control, communications, and intelligence. While none of these scenarios asks the United States or its air force to do anything either is not capable of doing, the Russian setting presents unique and serious challenges. Geographical constraints of distance, terrain, and weather conditions create an unknown and unpredictable environment. Furthermore, many of the same events that increase the probable need for U.S. intervention will also make that intervention more operationally challenging.

### The United States Can Take Steps to Limit Russia's Decline and to Prepare for Potential Crises

To minimize the risks inherent in these and other scenarios, U.S. policy toward Russia should focus on the twin goals of limiting Russia's decline and planning U.S. military response to potential crises. This study posits that improving U.S.

relations with Russia is the best strategy for preventing a crisis situation in that country. By doing so, the United States can gain access to critical information, help mitigate Russia's decline, and build cooperative relationships necessary for dealing with a disaster. Recommendations include the following:

- Continue to publicly emphasize Russia's role in the global war on terrorism.
- Take steps to improve Russia's cooperation with NATO.
- Cooperate on the development of missile defense technology.
- Work with Russia to develop Caspian oil and gas exports.
- Integrate Russia into U.S. relations with Central Asian and other post-Soviet states as well as elsewhere.
- Assist Russian economic reform efforts by encouraging U.S. investment and helping Russia to create a legal structure to attract investors.
- Intensify efforts to improve nuclear safety and security in both weapons and nonweapons sectors in Russia.
- Continue cooperation between the Federal Emergency Management Administration (FEMA) and its Russian counterpart, EMERCOM, as a model for closer ties in other areas, including military ties.

At the same time, preparing the U.S. military for potential crises in Russia requires a new approach to military planning for the region. Little operational planning in recent years has even touched upon the possibility of U.S. forces carrying out tasks in or near Russia itself. European Command, Pacific Command, and Central Command will all need to plan and prepare for contingency responses in and around Russia. The Air Force should play a leading role in this planning. For example, strengthening military-to-military contacts with Russian counterparts will help the Air Force to build habits of cooperation and to gather crucial information about airfields, infrastructure, local military response, and other operational considerations. Furthermore, in the event of a future downturn in relations, the Air Force can take advantage of bilateral cooperation programs such as the Cooperative Threat Reduction Program and FEMA cooperation with EMERCOM to continue information-gathering and to identify regions where crises could occur. All of these tasks will require the allocation of additional resources and assets.

MR-1442-AF, *Assessing Russia's Decline: Trends and Implications for the United States and the U.S. Air Force*, Olga Oliker, Tanya Charlick-Paley

## Publications

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MR-305/1-AF, *Effects of the Coalition Air Campaign Against Iraqi Ground Forces in the Gulf War*, Stephen T. Hosmer.

The study examines the effectiveness of the Coalition air campaign against Iraqi ground forces in the Kuwait Theater of Operations during the 1991 Gulf War. It assesses how and the extent to which the air campaign met its assigned goals and analyzes its contributions to the rapid and low-cost victory achieved by Coalition forces. The author draws upon interrogations of Iraqi prisoners of war and "line crossers" (deserters) to describe and assess the corrosive effects of the Coalition bombing on Iraqi troop morale and battlefield behavior. It is one of a Project AIR FORCE series documenting the results of a study of the Desert Storm campaign. (Limited distribution)

MR-1209-AF, *Space Weapons, Earth Wars*, Bob Preston, Dana J. Johnson, Sean J.A. Edwards, Michael Miller, Calvin Shipbaugh.

Space weapons have been debated intensely in the past. The latest controversy is over their use for ballistic missile defense. However, this is not the only possible role for space weapons, and that raises a further concern: What if an adversary were to develop such weapons? Before the United States decides to acquire or forgo space weapons for terrestrial conflict, there should be a broad public discussion of what such weapons can do, what they will cost, and the likely consequences of acquiring them. The authors of *Space Weapons, Earth Wars* seek to aid this discussion not by arguing for or against space weapons but by describing their attributes, classifying and comparing them, and explaining how each might be used. The authors also explore how a nation might decide to acquire such weapons and how other nations might react.

MR-1216-AF, *A Global Access Strategy for the U.S. Air Force*, David A. Shlapak, John Stillion, Olga Oliker, Tanya Charlck-Paley.

The post-Cold War era has ushered in an unprecedented need for responsiveness on the part of all U.S. military services to fast-moving, rapidly evolving contingencies around the globe. Ready access to overseas installations, foreign territory, and foreign airspace has assumed particular importance to the United States Air Force (USAF), the majority of whose aircraft are configured to operate from bases relatively close to their intended targets. Accordingly, the authors

outline an approach that the USAF can take to secure such access across a wide range of potential contingencies. The report begins by analyzing the variables that have affected other countries' decisions either to grant or to deny the United States access, and it then discusses the tools that are available to the United States to help ensure such access in the future. Subsequently, the report evaluates the effects that less-than-optimal basing and access might have on future USAF operations and the manner in which such effects might be mitigated. The demands that military operations other than war might impose on the USAF are similarly assessed. Finally, the report offers a set of recommendations that, taken together, constitute the basis for a global access strategy aimed at better equipping the USAF to meet its access and basing needs—and hence to perform its missions both rapidly and effectively—in the future.

MR-1263-AF, *Supporting Expeditionary Aerospace Forces: Lessons from the Air War Over Serbia*, Amatzia Feinberg, Eric Peltz, James Leftwich, Robert S. Tripp, Mahyar Amouzegar, Russell Grunch, John Drew, Tom LaTourrette, Charles Robert Roll, Jr.

Over the past three years, Project AIR FORCE has studied options for configuring an Air Force Agile Combat Support (ACS) system that would enable the achievement of Expeditionary Aerospace Force (EAF) operational goals. This chain of research has led to the emergence of a structural framework consisting of a command and control system that can very quickly reconfigure combat support activities, forward operating locations (FOLs) from which to launch combat operations, a system of regionally oriented forward support locations (FSLs), a system of CONUS support locations (CSLs), and a distribution network capable of responsive two-directional distribution between FOLs, FSLs, and CSLs. The Air Force's ad hoc implementation of many elements of the framework to support the Air War Over Serbia (AWOS) offered opportunities to assess how well it worked and what the results imply for how the ACS system should be configured. The findings support the efficacy of the emergent ACS structural framework and the associated, but still evolving, Air Force support strategies. The AWOS experience was also valuable in identifying critical implementation issues in each of the five elements of the ACS structural framework. (Limited distribution)

MR-1314-AF, *Strategic Appraisal: United States Air and Space Power in the 21st Century*, Zalmay Khalilzad and Jeremy Shapiro (editors).

Change—in international relations, in technology, and in society as a whole—has become the idiom of our age. One example is an increasing recognition of the value of air and space assets for handling nearly every contingency from disaster relief to war and, consequently, increasing demand for such assets. This

volume—the fourth in the *Strategic Appraisal* series—draws on the expertise of researchers from across RAND to explore both the challenges and opportunities that the Air Force faces as it strives to support the nation's interests in a challenging technological and security environment. In the context of U.S. national security strategy, contributors examine the roles of air and space forces, the implications of new systems and technologies for military operations, and the role of nuclear weapons. Contributors also discuss the status of major Air Force modernization efforts and the “bill of health” of the Air Force as measured by its readiness to undertake its missions both today and in the future.

MR-1431-AF, *Supporting Expeditionary Aerospace Forces: Alternatives for Jet Engine Intermediate Maintenance*, Mahyar A. Amouzegar, Lionel A. Galway, Amanda Geller.

In recent years, the USAF has found it necessary to perform a number of overseas deployments—many on short notice—in support of a wide range of crises. Toward this goal, the Air Force has begun to reorganize itself to quickly deploy from the continental United States to appropriate forward operating locations worldwide. This report evaluates the manner in which Jet Engine Intermediate Maintenance (JEIM) shops can best be configured to facilitate such deployments. The authors examine a number of JEIM support options, which are distinguished primarily by the degree to which JEIM support is centralized or decentralized. They then assess the performance of each option for three jet engines: the F100-220, the F100-229, and the TF-34. They conclude that, for the F100-220 and F100-229, the most viable options involve establishing one or more JEIMs in the theater during war. For the TF-34, they recommend either that the above option be exercised or that a single, centralized JEIM be established in the continental United States.

MR-1436-AF, *Setting Requirements for Maintenance Manpower in the U.S. Air Force*, Carl J. Dahlman, Robert Kerchner, David E. Thaler.

Over the past decade, the USAF has faced a variety of unforeseen challenges. On one hand, a significant portion of the force has been engaged in a range of contingency as well as peacekeeping operations. On the other, a once-robust economy led many personnel to leave the force in unexpected numbers during the 1990s. The result has been a mismatch between Air Force taskings and available personnel. This report outlines the findings of a study that first reviewed the methodology that the Air Force uses to determine active-duty enlisted manpower requirements in aircraft maintenance and, second, investigated whether these requirements and their resulting authorizations have been underesti-

mated. The study assesses the Logistics Composite Model (LCOM), a statistical simulation model that the Air Force uses to gauge direct maintenance man-hours, as well as the Air Force-wide regulations that establish ceilings on available hours. The report concludes that maintenance manpower requirements are in fact underestimated in the Air Force, largely because the service's manpower processes do not adequately account for all the tasks that maintainers in the field must undertake. Accordingly, the report recommends that Air Force policies and analytical tools be reexamined and appropriately refined to better reflect maintenance manpower needs.

MR-1438-AF, *Service Responses to the Emergence of Joint Decisionmaking*, Leslie Lewis, Roger Allen Brown, C. Robert Roll.

The 1986 Goldwater-Nichols legislation sought to counterbalance the decision-making authority of the services by giving the commanders in chief (CINCs)—now termed combatant commanders—a far greater voice in the determination of operational requirements. Toward this goal, the Chairman of the Joint Chiefs of Staff was empowered to integrate CINC requirements as well as to demonstrate how those requirements related to joint operational readiness. The authors examine how the Goldwater-Nichols legislation has affected decisionmaking within the Department of Defense and, more specifically, how the individual military services have responded to the changes brought about by that legislation. After describing the forces that underlay the passage of Goldwater-Nichols, the authors outline the manner in which the Departments of the Army, Navy, and Air Force have changed their decision models as well as their planning, programming, and budgeting processes in order to better respond to CINC demands. They conclude that all of the services have to varying degrees undergone some reorganization in response to the changes brought about by Goldwater-Nichols. However, those changes, which have largely reflected the cultures of the individual services, have been incremental at best and have yet to fully meet the challenge this new decisionmaking environment has posed.

MR-1442-AF, *Assessing Russia's Decline: Trends and Implications for the United States and the U.S. Air Force*, Olga Oliker, Tanya Charlick-Paley.

Continuing trends toward military, political, economic, and social decline in Russia threaten the interests of the United States and its allies. Moscow's capacity to govern is called into question by increasing crime and corruption as well as by political and economic regionalization. Both the military nuclear arsenal and the civilian nuclear power sector present risks of materials theft or diversion and the possibility of tragic accident. An increasingly aging and ailing population bodes ill

for Russia's future. Reversing the country's economic decline and rebuilding an effective military have proven difficult for the financially strapped government. While improvements, especially in the economic realm, are now evident, their sustainability is far from certain. The future development of these trends is critical to U.S. interests. Organized crime in Russia is part of a multinational network with links to global and local terror. Nuclear material from Russia could fall into the hands of terrorists. Russia is a major oil and gas producer and transit state, and the U.S. government has identified energy interests as key to national security. A humanitarian crisis in Russia could threaten U.S. allies with refugee flows, environmental crisis, or conflict spillover. In many scenarios, it seems likely that the United States would respond. If so, the Air Force is certain to be called upon for transportation and perhaps military missions in a very demanding environment.

MR-1471-AF, *Measuring Interdiction Capabilities in the Presence of Anti-Access Strategies: Exploratory Analysis to Inform Adaptive Strategy for the Persian Gulf*, Paul K. Davis, Jimmie McEver, Barry Wilson.

The authors discuss how U.S. capabilities for interdicting invading ground forces in the Persian Gulf can be adapted over time to maintain the ability to achieve an "early halt" or to counter maneuver forces in other plausible campaigns. They emphasize exploratory analysis under massive uncertainty about political and military developments and about the detailed circumstances of conflict. A specialized model used for "mission system analysis" helps identify *critical enablers* of early-halt capability: deployment; immediate command, control, intelligence, surveillance, and reconnaissance; ability to employ interdiction forces quickly; and weapon effectiveness. The United States should expect threatened or actual use of mass-casualty weapons against its forces and regional allies as well as enemy attempts to act quickly and with short warning. However, the threat's size and quality may be less than is usually assumed. On the military side, the authors characterize parametrically the conditions for a successful early halt, thereby identifying high-priority strategic hedges, capability developments, and potential adaptations. The analysis considers joint forces for interdiction and synergy with rapidly employable ground forces. On the political side, the authors note the premium on forward basing, aggressive use of ambiguous warning, and long-range bombers. Continued enforcement of red-line constructs could greatly improve the likelihood of decisive response to ambiguous warning. Countering anti-access strategies would be enhanced by negotiating use of more-distant bases and logistic preparation. It will be increasingly unwise to assume use of forward bases, even if technical analysis suggests that the bases could operate under attacks with mass-casualty weapons.

MR-1473-AF, *Innovative Development: Global Hawk and DarkStar—Their Advanced Concept Technology Demonstration Program Experience, Executive Summary*, Jeffrey A. Drezner, Robert S. Leonard.

In 1994, the Defense Advanced Research Projects Agency and the Defense Airborne Reconnaissance Office launched a joint initiative to overcome the impediments that had hampered past unmanned aerial vehicle (UAV) development. This effort—designated the High-Altitude Endurance Unmanned Aerial Vehicle Advanced Concept Technology Demonstration (HAE UAV ACTD) program—applied an innovative acquisition strategy to the development of two UAVs: one conventionally configured (Global Hawk) and the other with a low-observable configuration (DarkStar). The report summarizes the major research findings regarding the HAE UAV ACTD program's acquisition strategy. The authors conclude that, despite DarkStar's cancellation and despite overall program cost growth and schedule slippage in basic design and test of the two HAE UAV concepts, the ACTD program accomplished its primary objective by successfully demonstrating the military utility of a UAV with a continuous, all-weather, wide-area surveillance capability. Although the program's single requirement—the unit flyaway price—was not met, the requirement did promote cost consciousness while at the same time preventing the imposition of additional system capabilities during the basic system development. The authors found that the program's use of Other Transaction Authority lent considerable flexibility to the effort. While the program's designation as an ACTD imposed cost and schedule boundaries that constrained system development, it also provided a high degree of flexibility to adjust the program execution. Areas of risk were addressed as they arose, and early flight test experience was assimilated into continuing system development efforts. Relatively modest changes in up-front planning processes, the structured participation of operational users early in the program, and contract language regarding oversight processes and incentives should help ensure successful application of the acquisition strategy to a broader range of systems.

MR-1474-AF, *Innovative Development: Global Hawk and DarkStar—HAE UAV ACTD Program Description and Comparative Analysis*, Robert S. Leonard, Jeffrey A. Drezner.

Over the past three decades, efforts to develop unmanned aerial vehicles have been severely hampered by escalating costs, slipped schedules, and disappointing operational results. Recently, however, the Defense Advanced Research Projects Agency, in conjunction with the Defense Airborne Reconnaissance Office, launched an initiative—designated the High-Altitude Endurance Unmanned

Aerial Vehicle Advanced Concept Technology Demonstration (HAE UAV ACTD) program—whose objective was to overcome these deficits through the use of a new and innovative acquisition policy. The authors evaluate several key elements of this new strategy to determine their effect on the development of two air vehicles: the first a conventional vehicle (Global Hawk) and the second a low-observable configuration (DarkStar). They find that the ACTD approach required that the entire development effort be planned at the program's inception, which proved to be a detriment to the effort as a whole. In addition, the program's single requirement—a \$10 million unit flyaway price—proved unattainable and was eventually abandoned. At the same time, the program's designation as an ACTD, its use of Other Transaction Authority, and its delegation of considerable management responsibility to contractors greatly streamlined the oversight process and lent considerable flexibility to the effort. As a direct result of these factors, the Global Hawk program was judged to have successfully and cost-effectively produced a continuous, all-weather, wide-area surveillance capability for future warfighters. The authors thus conclude that although the DarkStar program was canceled before its capabilities could be fully demonstrated, the HAE UAV ACTD program was in aggregate a success.

*MR-1475-AF, Innovative Development: Global Hawk and DarkStar—Flight Test in the HAE UAV ACTD Program*, Jeffrey A. Drezner, Robert S. Leonard.

The past three decades have seen a number of less-than-successful efforts to develop high-altitude unmanned aerial vehicles. In 1994, the Defense Advanced Research Projects Agency, in conjunction with the Defense Airborne Reconnaissance Office, initiated an effort—designated the High-Altitude Endurance Unmanned Aerial Vehicle Advanced Concept Technology Demonstrator (HAE UAV ACTD)—whose goal was to facilitate the development of UAVs through the use of a new and innovative acquisition strategy. The authors address the effect of that acquisition strategy on the flight test program of the two air vehicles: the conventional Global Hawk and the low-observable DarkStar. They find that because DarkStar was canceled after having logged only 6.5 flight hours, not enough flight experience was accumulated to allow for an understanding of the vehicle's flight characteristics or military utility. By contrast, Global Hawk accumulated ample experience to permit a demonstration of its military utility, and it achieved a level of performance that was close to predicted goals. The precise effect of the HAE UAV acquisition strategy remains the subject of debate. The strategy did, however, influence some key aspects of the flight test program, most notably its increased contractor involvement and its early operational testing in the form of user demonstrations. The flight test program also served to illustrate

the vital need for early involvement of operational users to bolster the capabilities and perspective of the contractor.

MR-1476-AF, *Innovative Development: Global Hawk and DarkStar—Transitions Within and Out of the HAE UAV ACTD Program*, Jeffrey A. Drezner, Robert S. Leonard.

Over the past three decades, a number of attempts have been made to develop unmanned aerial vehicles, but many of these efforts had disappointing results. Recently, however, the Defense Advanced Research Projects Agency (DARPA), in conjunction with the Defense Airborne Reconnaissance Office, launched an effort—designated the High-Altitude Endurance Unmanned Aerial Vehicle Advanced Concept Technology Demonstration (HAE UAV ACTD) program—whose objective was to overcome past constraints in UAV development through the use of a new acquisition strategy. The authors assess two transitions of the HAE UAV ACTD program—the first from DARPA to Air Force management and the second from an ACTD to a Major Defense Acquisition Program (MDAP)—to determine which elements of the program’s novel acquisition strategy facilitated these transitions and which engendered problems. The authors find that, in aggregate, the innovative acquisition strategy adopted in the HAE UAV ACTD program successfully achieved its key goals: demonstrating a new operational concept at a lower cost and in a shorter time frame than would have been possible with a traditional acquisition approach. However, although the transition from the ACTD construct to an MDAP was ultimately successful, it posed a number of challenges, many of which stemmed directly from its acquisition strategy. To circumvent these problems in the future, the authors recommend modifications to the strategy.

MR-1477-USJFCOM/AF, *Effects-Based Operations (EBO): A Grand Challenge for the Analytical Community*, Paul K. Davis.

Effects-based operations (EBO) are defined here as operations conceived and planned in a systems framework that considers the full range of direct, indirect, and cascading effects—effects that may, with different degrees of probability, be achieved by the application of military, diplomatic, psychological, and economic instruments. The report suggests principles for sharpening discussions of EBO, for increasing the rigor of those discussions, and for building the key ideas of EBO into analysis for defense planning, experimentation, and operations planning. It then illustrates the principles with explicit models. Finally, it sketches a possible research program to enrich the base for studying and practicing EBO.

MR-1487-AF, *How Should the U.S. Air Force Depot Maintenance Activity Group Be Funded? Insights from Expenditure and Flying Hour Data*, Edward G. Keating, Frank Camm.

The authors analyze how Air Force Materiel Command (AFMC) depot-level expenditures relate to operating command activity levels, or flying hours. They examine the recorded expenditures of AFMC's Depot Maintenance Activity Group (DMAG) and relate mission design-specific DMAG repair expenditures to various lags of fleet flying hours. Across a variety of weapon systems, they find that, although both flying hours and DMAG repair expenditures for component repair vary considerably month-to-month, there is no consistent, cross-system relationship between the series. The apparent lack of systematic correlation between DMAG expenditures and fleet flying hours argues for an alternative approach to budgeting and internal pricing. The results are consistent with multipart pricing. Under such an approach, AFMC would receive a budget to pay for its fixed costs, and operating commands would no longer face prices that include DMAG fixed costs that are unrelated to demands from the operating commands.

MR-1489-AF, *An Economic Framework for Evaluating Military Aircraft Replacement*, Victoria A. Greenfield, David Persselin.

Aging aircraft, burdensome operating and support costs, and maintenance uncertainties have led the USAF to ask when and how to replace its fleets. In response, Project AIR FORCE has developed an economic framework to aid in identifying optimal replacement strategies that recognize trade-offs among costs and explicitly incorporate the effects of age and uncertainty. In their discussion of the framework, the authors suggest that age may contribute to higher and less-predictable costs, as may workforce reductions, depot closures, and spare parts shortages. But when is it time to replace aircraft? The replacement problem lends itself well to economic modeling, and an economic framework can help the military develop a systematic approach to replacement decisionmaking. The authors identify an optimal replacement strategy for a generic fleet, comparing the least-cost solutions with and without uncertainty and testing the sensitivity of the results to key parametric assumptions. They also evaluate policy implications and suggest opportunities for future research.

MR-1496-AF, *Enhancing Dynamic Command and Control of Air Operations Against Time Critical Targets*, Myron Hura, Gary McLeod, Richard Mesic, Philip Sauer, Jody Jacobs, Daniel Norton, Thomas Hamilton.

During the 1990s, U.S. air operations produced disappointing results against adversary mobile forces that employed camouflage, concealment, and deception

techniques and shoot-and-scoot tactics. In this report, the authors summarize research intended to help the Air Force develop enhanced dynamic command and control and battle management (DC2BM) of intelligence, surveillance, and reconnaissance assets and shooter assets in air operations against such time critical targets (TCTs). It identifies four mission areas in which existing DC2BM capabilities are inadequate: counter-air operations against cruise missiles, theater missile defense counterforce operations against tactical ballistic missile transporter-erector-launchers, suppression of enemy air defenses in the context of strike missions against targets defended by advanced air defenses, and interdiction of small-unit ground forces intermingled with the civilian population. The authors conclude that DC2BM improvements should focus on (1) refining concepts of operations as well as tactics, techniques, and procedures and developing an end-to-end, scalable functionality for operations against TCTs; (2) building a robust, collaborative, distributed environment; (3) extensively automating the applications for performing DC2BM functions; and (4) synchronizing the new applications with a Web-enabled, integrated-software Theater Battle Management Core System.

MR-1521-AF, *Integration of Air and Space: Focus on Command and Control*, Myron Hura, Gary McLeod, Jody Jacobs, Richard Mesic, Manuel Cohen, Philip Sauer.

To fight the nation's wars, the USAF employs air and space forces. However, the two are controlled in separate chains of command. The level of integration of air operations and space operations to date has been achieved primarily because of the recognized value of space systems to other force elements. However, the current integration process will be insufficient as future U.S. space forces and missions mature and as adversaries begin to oppose U.S. space systems. More proactive and collaborative efforts by the USAF, the other military services, joint-service organizations, and intelligence organizations will be needed if new space systems are to achieve their potential. The authors identify key issues and areas that the Air Force should address in developing and selecting new integration initiatives for the command and control of air and space forces.

MR-1528-AF, *The Persian Gulf in the Coming Decade: Trends, Threats, and Opportunities*, Daniel L. Byman, John R. Wise.

This study examines likely challenges to U.S. interests in the Persian Gulf, identifies key uncertainties and trends, and assesses the implications of those trends for the United States. The authors find there is a declining threat from Iraq and Iran, with shifting military balances and weakness, although weapons of mass

destruction (WMD) remain a concern. Internal threats to regional partners include a fraying social contract—unemployment is growing and governments are less able to provide services. There is potential for unrest and sudden large refugee flows. Economic problems contribute to limited momentum for reform, and the U.S. presence and policies may exacerbate problems. The authors weigh possibilities for dramatic regime change in Iraq or Iran and conclude that, while many trends in the region are positive, daunting problems remain. The United States should focus less on the conventional military threat and more on the risk of WMD and possible instability or domestic unrest among several Gulf partners. It should also attempt to minimize any deleterious effects of the U.S. military presence in the region. (The analysis was completed before the September 11, 2001, terrorist attacks.)

MR-1536-AF, *Supporting Expeditionary Aerospace Forces: An Operational Architecture for Combat Support Execution Planning and Control*, James Leftwich, Robert Tripp, Amanda Geller, Patrick Mills, Tom LaTourrette, C. Robert Roll, Jr., Cauley Von Hoffman, David Johansen.

As part of a project to define the elements of a combat support system to help achieve USAF Aerospace Expeditionary Force goals, the authors provide a critical analysis of the current command and control (C2) architecture for combat support. Based on their analysis as well as on interviews with Air Force personnel, lessons from the Air War Over Serbia, and doctrinal changes and evolving practices, the authors set forth a series of structural concepts to improve execution of the C2 for combat support and remedy identified shortfalls in the current structure. The proposed architecture would allow the combat support community to quickly estimate requirements for force package options and to assess the feasibility of operational and support plans. To transition to the new architecture, the authors recommend summarizing and clarifying Air Force combat support doctrine and policy on C2, using feedback to monitor performance against plans, creating standing combat support organizations to promote stability in turning from one contingency to the next, cross-training operations and combat support personnel on each other's roles, and fielding improved information and decision-support tools.

MR-1537-AF, *Going Global? U.S. Government Policy and the Defense Aerospace Industry*, Mark A. Lorell, Julia Lowell, Richard M. Moore, Victoria Greenfield, Katia Vlachos.

A dramatic decline in overall defense authorizations since the end of the Cold War has led both the U.S. and European aerospace industries to undergo exten-

sive consolidation—a trend that has led in turn to a significant growth in cross-border business relationships. Yet while globalization has the potential to increase competition, foster innovation, encourage fair pricing, and promote interoperability among NATO allies, it also poses potential challenges, particularly with regard to the proliferation of advanced U.S.-developed military technologies. Accordingly, the authors examine aerospace industry globalization trends with a view toward determining how and to what extent globalization can best be managed to further the Air Force's economic and political-military objectives while minimizing possible risks. The report confirms that the recent proliferation of cross-border business relationships has significant potential for promoting allied standardization while simultaneously reducing costs. At the same time, however, enduring concerns over technology transfer issues, together with the increasing competitiveness of European and other multinational firms, may well undermine standardization efforts by encouraging the formulation of indigenous solutions. The authors conclude that further research is needed to fully clarify the manner in which the Air Force should respond to the continued consolidation and globalization of the aerospace industry.

MR-1550-AF, *Absorbing Air Force Fighter Pilots: Parameters, Problems, and Policy Options*, William W. Taylor, James H. Bigelow, S. Craig Moore, Leslie Wickman, Brent Thomas, Richard Marken.

The Air Force currently faces unprecedented problems in its efforts to provide adequate training for new and inexperienced pilots in its operational fighter units. On one hand, there are too few fighter pilots in the active component to meet current and anticipated demands. On the other, the number of new fighter pilots entering operational units currently exceeds the absorption capacity of the units, thereby yielding a degraded training environment that ultimately threatens to compromise military readiness. This report assesses the Air Force's training dilemma with a view toward finding ways to remedy it in both the short and long term. It defines the key parameters that influence a unit's absorption capacity, presents a best-case scenario on which to base numerical analyses, and offers several options decisionmakers can exercise. Although there is no simple resolution to the Air Force's training problem, a thorough understanding of the dynamic processes involved in aircrew management, together with a comprehensive analytic framework, promises to greatly aid decisionmakers in their efforts to address this issue.

MR-1566-1-AF, *Air Force Compensation: Considering Some Options for Change*, James Hosek, Beth Asch.

Recruiting difficulties during the 1990s, as well as manning shortfalls in certain specialties, have prompted the Air Force to consider significant alterations to the compensation system. The authors first describe Air Force recruitment and retention and compare them to the situation in the other military services. They then examine the current pay system and suggest ways it could be strengthened: monitoring civilian wages more closely, reshaping the basic pay table to make basic pay grow increasingly rapidly with respect to rank, restructuring selective reenlistment bonuses to make them worth more, and revamping Hostile Fire Pay/Imminent Danger Pay from a flat monthly rate to a level that depends on the number of hostile episodes. The report also provides an initial assessment of two pay concepts: skill pay (intended to provide higher pay for certain valuable skills) and capability pay (intended to provide compensation and incentives for superior individual capability, especially current and prospective leadership potential). The authors discuss methods and standards for establishing these types of compensation and examine questions of fairness and the administrative and human costs of implementing new systems. Finally, they consider ways to analyze the effects and cost-effectiveness of skill pay and capability pay: microsimulation modeling, a demonstration experiment, and surveys to query Air Force personnel about their retention intentions under a large number of potential skill pay and capability pay alternatives.

MR-1572-AF, *Toxic Warfare*, Theodore Karasik.

The past several years have seen an increased interest in the use of toxic weapons—i.e., weapons that incorporate inexpensive and easily attained chemicals and industrial waste—on the part of both state and nonstate entities. Such weapons have been sought out because they are abundant and readily available and because they allow hostile entities to improve their capabilities within the context of asymmetrical warfare. Despite these trends, however, the level of threat such weapons represent has yet to be precisely determined. Accordingly, this report seeks to provide a qualitative overview of the threat toxic weapons pose as well as to identify key vulnerabilities the United States and the U.S. military face. The report describes the composition and sources of toxic weapons as well as their potential for harm, and it outlines the use of such weapons by state and nonstate actors over the past decade. The report then focuses on the implications of toxic weapon use both for U.S. forces engaged in military operations and for the U.S. homeland. The author concludes that toxic warfare must be better understood so that the threat can be more effectively incorporated into military and civilian crisis response planning.

MR-1596-AF, *Military Jet Engine Acquisition: Technology Basics and Cost-Estimating Methodology*, Obaid Younossi, Mark V. Arena, Richard M. Moore, Mark Lorell, Joanna Mason, John C. Graser.

As manufacturing processes and materials used in aircraft engine production change and new information on aircraft engine technology becomes available, cost-estimation techniques must be updated. In this report, the authors describe the results of research to develop a new methodology for estimating military jet engine costs. They first discuss the technical parameters that drive the engine development schedule, development costs, and production costs, and then they present a quantitative analysis of historical data on development schedules and costs. Their principal focus is on adding new observations to the cost-estimating database from earlier RAND studies and on updating the parametric relationships for aircraft engine costs and development time. The authors define a series of parametric relationships for forecasting the development cost, development time, and production cost of future military engine programs. Rotor inlet temperature, full-scale test hours, and whether an engine is new or derivative are found to be significant cost-estimating measures.

MR-1606-AF, *The Stryker Brigade Combat Team: Rethinking Strategic Responsiveness and Assessing Deployment Options*, Alan Vick, David Orletsky, Bruce Pirnie, Seth Jones.

The U.S. Army perceives a gap between its current light and heavy forces: light forces deploy rapidly but lack staying power; heavy forces have immense power but take too long to deploy. To close this gap and to experiment with new tactics, the Army has begun a transformation process that will field medium-weight Stryker Brigade Combat Teams beginning in 2003. The Army goal is to make these brigades light enough to deploy anywhere in the world in four days. To assess deployment and basing options, the study team developed a simple spreadsheet that calculated transit times, loading and unloading times, and airfield throughput. It used military planning factors to determine aircraft usage rates, and maximum loads and ranges.

The authors conclude that the Stryker brigade cannot deploy by air or sea from bases in the United States to key regions in 4 days. Deployment times range from 9 days (Colombia) to 21 days (Afghanistan). In most scenarios, even if unlimited numbers of aircraft were available, airlift would still be constrained by the condition of receiving airfields. In some scenarios, the brigade would close as rapidly with sealift but still fall well short of the 4-day goal. However, using combinations of airlift and fast sealift to move forces from forward bases or preposition sites,

forces could reach key regions in 5 to 9 days, and most of the globe could be covered in two weeks—a great improvement over historic deployment times for motorized forces.

DB-334-AF, *Implementing Best Purchasing and Supply Management Practices: Lessons from Innovative Commercial Firms*, Nancy Y. Moore, Laura H. Baldwin, Frank Camm, Cynthia R. Cook.

Because the U.S. Air Force spends over one-third of its budget for purchased goods and services in nonweapon categories, such purchases are a prime target area in which to seek performance improvements and cost savings. Prompted by a need for improved performance from its supply base, the Air Force has become increasingly aware of the advantages of using market research, contract consolidation, supply base rationalization, and other leading purchasing and supply management (PSM) practices in its dealings with suppliers. To aid the Air Force in its PSM efforts, Project AIR FORCE examined how innovative commercial firms implement such practices in their purchases of good and services. After a review of the academic and trade literature, the study team conducted a series of elite interviews using a structured questionnaire to gather primary data from “best in class” commercial firms. The key findings are that (1) innovative commercial firms are moving to a strategic, goal-oriented approach to PSM, (2) implementing new PSM practices can take a number of years and often requires significant, permanent change throughout the organization, and (3) the Air Force needs strategies to sustain continuity of support for serious PSM change from one leadership team to the next.

DB-382-AF, *Assessing Unit Readiness: Case Study of an Air Force Mobility Wing*, David E. Thaler, Carl J. Dahlman.

The U.S. Air Force has recently confronted a multiplicity of challenges in its efforts to maintain military readiness in the face of constrained resources and demanding contingency requirements. This documented briefing explores the nature and extent of such challenges within the air mobility community by focusing on the 60th Air Mobility Wing (AMW) at Travis Air Force Base, California. Drawing from extensive research as well as from detailed surveys of unit personnel, the authors conclude that the 60th AMW has in fact faced a variety of stringent and often-competing challenges, including dramatic fluctuations in the demand for airlift and tanker support, a decline in experience mix brought about by the loss of experienced pilots and maintainers to the civilian sector, a consequent need for the training of new and inexperienced personnel, and a maintenance workload burdened by frequent shortages of parts and “out-of-hide”

responsibilities. The events of September 11 eased many of these challenges, but this is seen as only a temporary respite. The authors also find that senior personnel have borne the brunt of these challenges by having to sustain high levels of productivity while simultaneously ensuring that more junior personnel are adequately trained. They conclude that the problems facing the 60th AMW would appear to typify those of Air Force mobility wings in general. While the problems do not prevent the wing from meeting its short-term operational demands, these compensatory measures cannot be sustained over the longer term.

DB-388-AF, *Implementing Performance-Based Services Acquisition (PBSA): Perspectives from an Air Logistics Center and a Product Center*, John Ausink, Laura H. Baldwin, Sarah Hunter, Chad Shirley.

The U.S. Air Force is implementing performance-based practices in its service contracts to improve quality and reduce costs. Earlier Project AIR FORCE research examined implementation in installation support services. The project has now examined purchased services that support weapon system development and sustainment ("systems" services). Under performance-based services acquisition (PBSA), buyers should (1) describe what service is desired—not how to do it, (2) use measurable performance standards and quality assurance plans, (3) specify procedures for reductions in fee or price when services do not meet contract requirements, and (4) include performance incentives where appropriate. The authors conducted interviews at an Air Logistics Center and a Product Center to learn whether and how service contracts included these performance-based practices. Many interviewees at the two Centers felt that it is difficult for systems service contracts to satisfy all four of the PBSA criteria. To use "measurable performance standards," for example, some personnel believe that the desired result of a service must be known in advance and objective data must be collected frequently to measure performance against that result. This cannot be easily done for many systems services such as engineering support and advisory and assistance services. Despite this difficulty, however, both Centers use a performance-based approach that applies the other three criteria to purchase a range of services, and personnel generally felt that they can determine and convey whether the contractor met their needs. The authors conclude that many of the approaches used by the Centers satisfy the intent of the criteria.

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